



The Journal
2018



Editorial

School is a learning journey in so many ways. For the twelve authors of the works contained in *The Journal*, these pieces are the culmination of their academic journey here at the RGS. It is so pleasing to see such diverse paths, to see pieces of such individuality, creativity and academic rigour. I count it such a privilege to be the *Head of Scholarship* in a school where I am routinely, and with great humility on the part of our students, astounded by their capabilities. From visualising the dynamics of water molecules, through to a sharp defence of modern Islam, to a paper on Cystic Fibrosis presented at a conference to the *Royal College of Medicine*, to an expose of Pericles' tyrannical temperament: the extraordinary level of intellectual sophistication shown in these works of scholarship will, I hope, take anyone fortunate enough to read this *Journal* on an intellectual journey of their own.

Mr CS Bradford
Head of Scholarship







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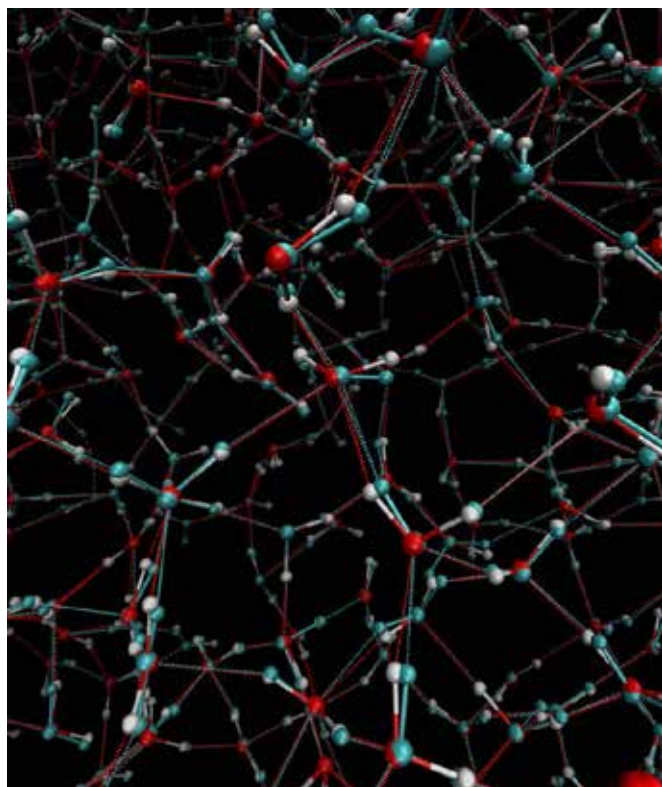


A study of the normal modes of water molecules in the classical & quantum worlds

Adam Wills, supervised by Professor Stuart Althorpe of the University of Cambridge

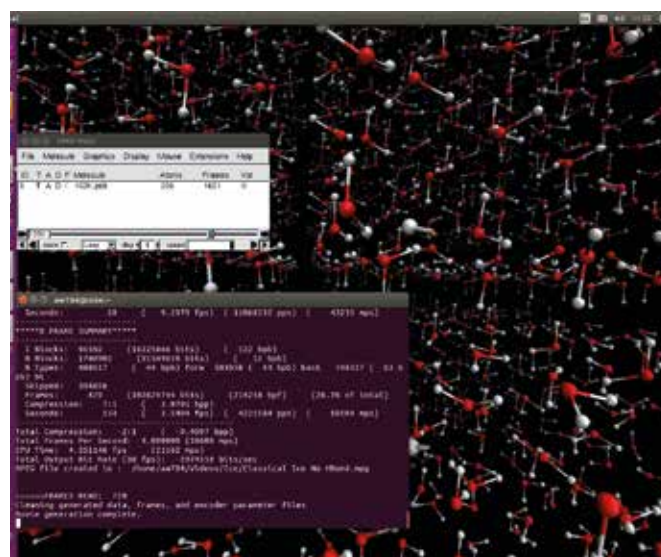
ABSTRACT

The H_2O molecule, despite appearing rather simple, is notoriously difficult to model. Both liquid water and ice have challenged chemists for nearly a century. My CREST project takes a visual approach to examining the movements of water molecules, both individually and collectively, using the program VMD (visual molecular dynamics) to produce videos and images of water in the liquid and solid states. I will describe the already-known dynamics that govern these simulations as well as the newer model that is being developed by the researchers I worked with in the Department of Theoretical Chemistry at the University of Cambridge.



INTRODUCTION

The simulations that I ran can be split into two overall classes: the classical and the quantum models. The classical simulations rely on mechanics developed in the centuries following Sir Isaac Newton's work. They consider the locations of the oxygen and both hydrogen atoms to be perfectly known (and therefore there is supposed to be no de-localisation of the atoms). The interactions between the molecules are considered to be very standard:



Manipulating a classical ice model in VMD

- London forces occur due to electrons within the water molecules being instantaneously distributed unevenly across the molecule, thus causing a dipole. This causes an induced dipole in neighbouring water molecules and thus there is electrostatic attraction between the molecules.
- Dipole-dipole forces occur because the oxygen atom has a higher electronegativity than the two hydrogen atoms, resulting in a permanent polarity to the water molecule. This also results in attractions between molecules.
- Hydrogen bonds are the strongest of the intermolecular interactions and are the primary reason for water's high melting and boiling points. The difference between the electronegativities of the oxygen and hydrogen at either end of the OH bonds is high and so the hydrogen atom has a very large positive dipole formed on it. As a result, it becomes attracted to the lone pairs of electrons on the oxygens of neighbouring molecules. These interactions are approximately 10% of the strength of a covalent bond.

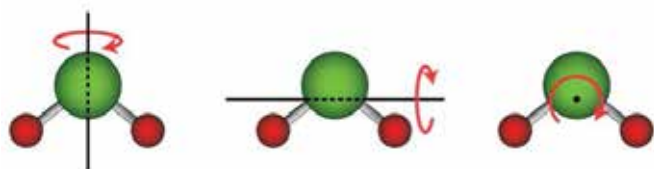
NORMAL MODES

A 'mode' in physics or chemistry can be thought of as a type of motion. Normal modes are a collection of these that are orthogonal to each other, as suggested by their name. In water and other molecules, each of the normal modes combine to produce an overall motion that can appear random. However, normal modes are well understood and I will give an introduction to them before showing how I simulated them.



AN INTRODUCTION TO NORMAL MODES

It is important one understands the movement of molecules generally, instead of specifically examining water. The degrees of freedom of a system are defined as 'The number of parameters of the system that may vary independently' (wikipedia.org/wiki/Degrees_of_freedom). If the number of nuclei in a molecule were to be represented by x , then $3x$ gives the total number of degrees of freedom of a molecule (an x , y and z coordinate for each atom). However, not all of these are relevant to the study of normal modes, assuming that there is no overall field (such as an electromagnetic field) acting. Three of the degrees of freedom are described as translational degrees of freedom: the movement of the molecule in its entirety in 3-dimensional space. Rotational degrees of freedom describe the change to the molecule's orientation that results from a rotation about a given axis. For linear molecules, there are only two of these because a rotation along the line of the nuclei does not give rise to a distinct change. For non-linear molecules, there are three of these:



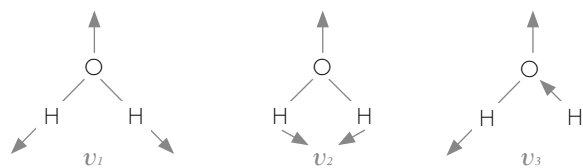
Rotations about all three axes cause a distinct change in the orientation of the water molecule.

Translational and rotational degrees of freedom do not give rise to normal modes (assuming there is no overall field acting, such as an electromagnetic field); it is only the vibrational degrees of freedom that do this. Thus, the number of vibrational degrees of freedom is given by:

$$3x-5 \text{ for linear molecules}$$

$$3x-6 \text{ for non-linear molecules}$$

The number of degrees of freedom corresponds to the number of independent normal modes of a molecule. For water (non-linear), this is $3 \times 3 - 6 = 3$. The three normal modes of a water molecule are shown:



ν_1 has been chosen by convention to denote the symmetric stretch, ν_2 the bending and ν_3 the asymmetric stretch. This convention is common to all non-linear molecules.

USING MOLECULAR SYMMETRY AND GROUP THEORY

All normal modes are connected to the symmetry of the molecule. The best way to describe the overall symmetry of a molecule is by associating it with a certain point group, which is an easy way to describe all the symmetries a certain molecule contains. By doing this, the normal modes of the molecule can be predicted. This technique is old yet still useful today; it is known to have been used by the American chemist Edgar Bright Wilson in 1934. In determining the point group of a molecule, we must utilise arguably one of the most pure forms of mathematics: group theory. It is the use of such a pure form of mathematics in the study of the real world that makes this topic so interesting to me.

The symmetry operations that apply to a particular molecule form a mathematical structure known as a 'group', which means this collection has four characteristic properties:

I Closure Property

- ☐ Informally: Successively applying any two of the transformations in the group results in an overall transformation that is also in the group. This is like taking two members integers and being sure that their product is also going to be an integer (the integers are a group).
- ☐ Formally: Given two elements, $x, y \in G$, $x \cdot y$ is an element of G .

II Associative Property

- ☐ Informally: The order in which successive transformations are applied does not matter. This is like saying $(2 \cdot 3) \cdot 5 = 2 \cdot (3 \cdot 5)$.
- ☐ Formally: For all $x, y, z \in G$, $(x \cdot y) \cdot z = x \cdot (y \cdot z)$

III Identity Element

- ☐ Informally: There has to be an element in the group, commonly abbreviated to E (short for 'Einheit' in German, meaning 'unity'), which makes no change when combined with another transformation. This is simply leaving the molecule as it is. This seems rather pointless to explicitly mention; however, it is important for defining the properties of a group; it is the same as multiplying any number by one.
- ☐ Formally: There must exist an element $E \in G$ for which $x \cdot E = x$ for all $x \in G$. E is the identity element.

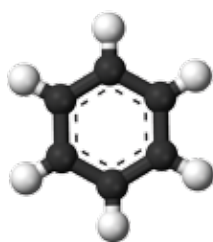
IV Inverse Element

- ☐ Informally: For all transformations in the group, there must be another transformation that does the reverse. Therefore, applying these two transformations successively gives rise to no change.
- ☐ Formally: For each element $x \in G$, there must exist an element $x^{-1} \in G$ where $x \cdot x^{-1} = E$.

There are five types of symmetry that we can use to fully describe the symmetries of a molecule:

I Symmetry Axis (Proper Rotation)

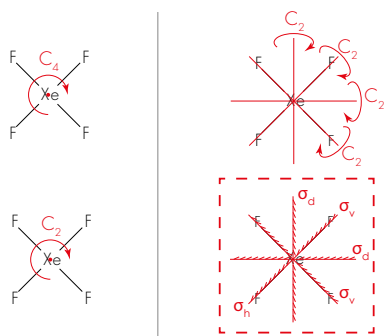
This is an axis around which rotational symmetry occurs; if the molecule is rotated by a certain degree around this axis the result will be indistinguishable from the start. They may have different levels of symmetry; if a rotation of $(360/n)$ degrees leads to a molecule indistinguishable from before, then the molecule is said to have C_n rotation about that axis. The axis with the highest level of rotational symmetry is known as the 'principal axis'.



Benzene, shown, has one axis C_6 axis, passing through the centre perpendicular to the ring; this is the principal axis. It also has six C_2 axes, running between opposite atoms and between the middles of opposite bonds.

II Plane of Symmetry

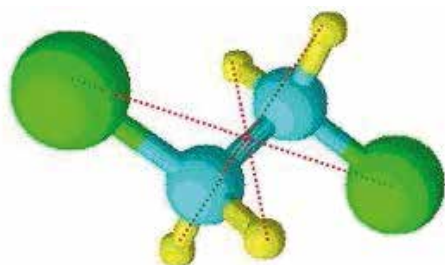
If a plane is drawn through the molecule and all atoms are transformed as far onto the opposite side of the plane as they were from the plane on their previous side and the result is indistinguishable from the original, this is a plane of symmetry. A plane parallel to the principal axis is considered to be vertical and one perpendicular to it is said to be horizontal. These symmetry planes are abbreviated to σ_v and σ_h respectively.



XeF_4 , with its square planar structure, has a significant number of symmetry elements, including two vertical symmetry planes and one horizontal symmetry plane. It also has two of a particular type of vertical symmetry plane: the dihedral plane σ_d . This occurs when the vertical symmetry plane bisects the angle between two C_2 proper rotation axes, both of which are perpendicular to the principal axis.

III Inversion Centre

If every atom in a molecule can be transformed diametrically and an equal distance through one particular point and become mapped onto an atom of the same type, this point is said to be an inversion centre and abbreviated to i .

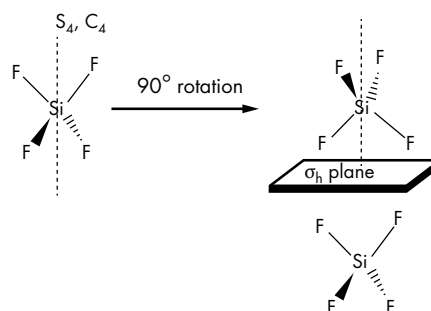


1, 2-Dichloroethane, while in the trans conformation, has only one type of symmetry other than the identity element: an inversion centre in the centre of the C-C bond.

IV Rotation-Reflection Axis (Improper Rotation)

This is simply a combination of a symmetry axis and a symmetry plane. If a molecule can be rotated about an axis by $(360/n)$ degrees and then be reflected in the plane orthogonal to that axis

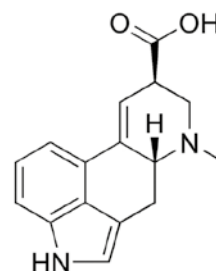
and the result is indistinguishable from the original, then this axis is an n -fold rotation-reflection axis. This can be abbreviated to S_n .



Silicon tetrafluoride, like all purely tetrahedral structures, has S_4 axes.

V Identity Element

Abbreviated to E , this is the trivial symmetry that leaving a molecule as it is will cause the result to be indistinguishable from the original. This is in accordance with the third characteristic listed above that allows molecular symmetry operations to be considered a mathematical group.



Lysergic acid, like many molecules with multiple chiral carbons, has E as its only symmetry element.

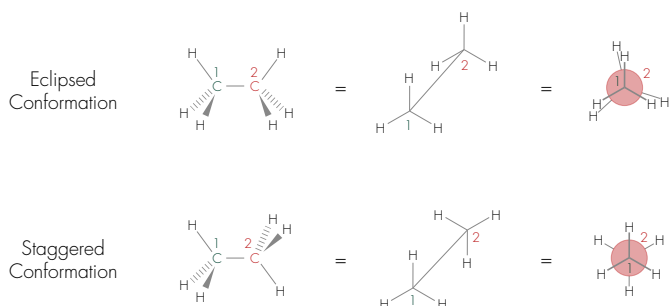
ASSIGNING A POINT GROUP

Once one knows all the symmetries that apply to a certain molecule, a point group can be assigned to it. This is useful for chemists as molecules with similar symmetries are likely to exhibit the same behaviours, particularly when in relation to whether they can be detected with IR and Raman spectroscopy. Point groups have names such as C_{3v} (molecules which undergo the identity operation, one C_3 axis and three σ_v planes) and so give some indication of the symmetry operations contained within it. The molecule in question, water, belongs to the C_{2v} point group, undergoing the identity operation, one C_2 axis and two σ_v planes. This seems fairly mundane so I will include a more exotic example:



Ferrocene, $\text{Fe}(\text{C}_5\text{H}_5)_2$, belongs to the D_{5d} point group and has two five membered carbon rings (staggered at 36° degrees to each other) joined by one iron atom. This has a myriad of symmetries including $5\sigma_d$ planes, an inversion centre and multiple S_{10} improper rotations.

It is worth mentioning that some molecules, non-rigid molecules, can have different molecular symmetries given their arrangement at any particular instant, called its conformation. For example, ethane will have different symmetries when in the staggered and eclipsed conformations shown:



Once a point group is assigned, it is possible to discover which normal modes the molecule will undergo using mathematics that is sadly too advanced for the purposes of this explanation.

VISUALISING THE NORMAL MODES OF WATER

The visualisation of both water and ice began with the generation of raw data using a water potential. This gave the locations of oxygen and hydrogen atoms in 3-dimensional space and detailed how they were connected to form H_2O molecules. For water, a unit cell of 128 molecules was created and for ice a unit cell of 96 molecules was made in order to best show the hexagonal structure. Each file contained these details written 1600 times, each one being one 'frame' (resulting in decidedly massive text files). Each frame had the coordinates of the atoms differing slightly so that they could be displayed one after another by VMD to produce an accurate trajectory of the water molecules in accordance with the water potential.

My first aim was to visually isolate each normal mode. Each of the normal modes of water occurs on a different time-scale: a symmetric or asymmetric stretch has a time period of approximately 10 femtoseconds (1×10^{-14} seconds), whereas the bending of the bond occurs once every 50 femtoseconds. A partial rotation of the whole molecule, whilst not a normal mode, occurs with a significantly longer time period. The most efficient strategy therefore for isolating each of these motions was to 'zoom in' on just one molecule and vary the rate at which the frames were read per second.

The OH bond stretches and contracts about 10% of its length. Because the movement is small, it was necessary to move the camera angle until it was perpendicular to the bond. View this here:

https://youtu.be/5sM4jV_Lj6k

Observing the molecular bending required a slightly faster frame-rate than for the stretching as well as a change in camera angle:

https://youtu.be/tXRtqQil6_U

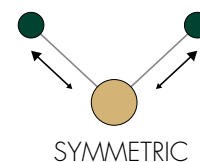
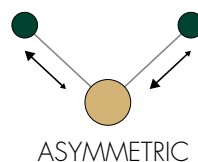
For good measure, I will include a video of a water molecule in partial rotation (rotating back and forth by approximately 30 degrees). This is not a normal mode and does not cause the absorbance of IR radiation, but it will become important when we examine the trajectories of atoms

through space. The frame-rate has been increased to a point where the length of the bond appears fixed.

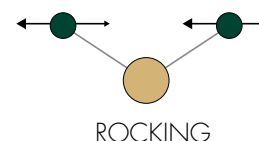
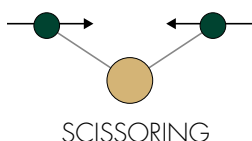
https://youtu.be/4SZ_V4gO1lI

The diagram below shows the six vibrational and rotational movements of water, only the first three of which are considered normal modes:

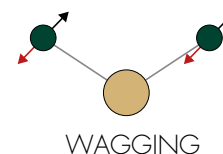
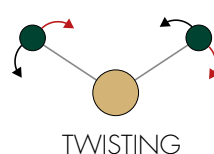
IN PLANE STRETCHING MOVEMENTS



IN PLANE BENDING MOVEMENTS



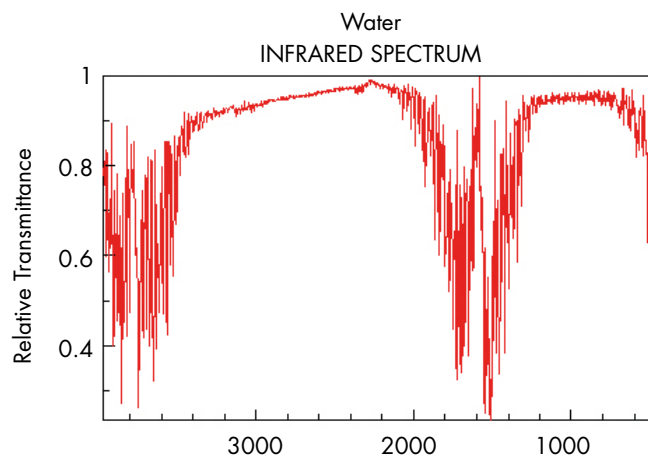
OUT OF PLANE BENDING MOVEMENTS



Rocking, twisting and wagging are all considered rotations about the three axes. The three rotations shown in the diagram on the second page are considered twisting, wagging and rocking respectively.

IR ABSORPTION

Water vapour accounts for 70% of all absorption of radiation in the atmosphere, therefore protecting humans. It absorbs radiation from the microwave to ultraviolet regions; however, it is the most powerful absorber of infrared.





The three normal modes of water can all be seen in the above spectrum:

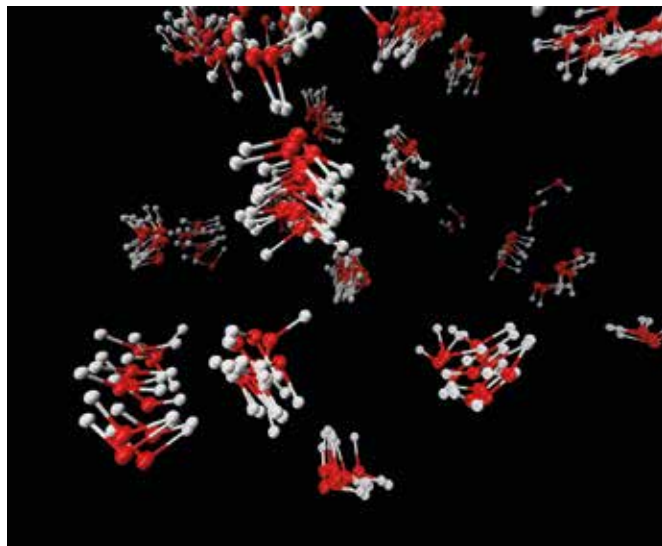
Normal Mode	Symmetric Stretch	Bend	Asymmetric Stretch
Approximate IR absorption wavenumber/cm ⁻¹	3652	1595	3750

The reason only these three (vibrational) movements are IR active is that they cause a change in the dipole moment of the water molecule, while rocking, twisting and wagging do not. This is because the periodic fluctuation of a molecule's dipole moment causes an interaction with the electromagnetic field that is infrared radiation. This interaction causes the absorption of radiation of the right frequency (energy) and a resultant rise in the amplitude of the molecule vibration.

A QUALITATIVE ANALYSIS OF THE COMBINATION OF NORMAL MODES ON WATER MOLECULES

In this section, I will give my own qualitative analysis of how the normal modes combine in water molecules and the resulting trajectories of the atoms through space, purely based on my own observations having worked with these models for several weeks.

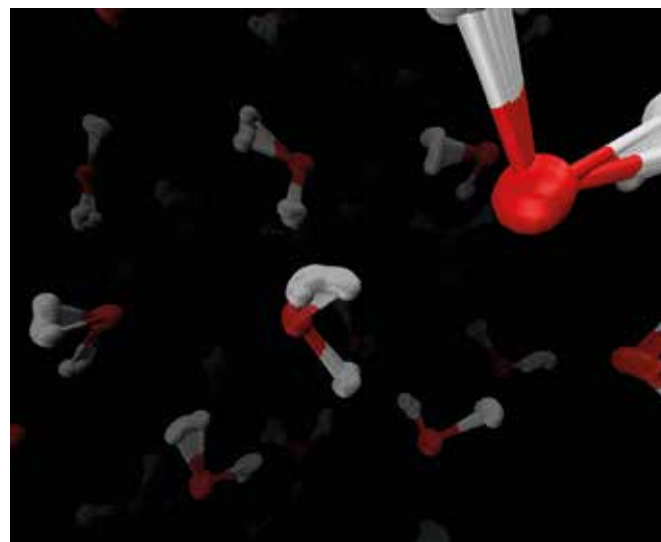
These observations are never 'clean' as each one has to combine the molecule's normal modes, rotations and its overall trajectory through space. I have found the best way to show these is not via videos but with photos showing multiple frames of the molecules' movements, overlapped on top of each other.



This image shows every hundredth frame in the animation of water molecules. This shows the overall trajectory of the molecules through space.

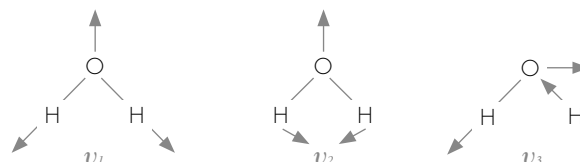
The image above illustrates the chaotic nature of the waters' movements and the need for careful analysis of the trajectories of the atoms.

BENDING



The image above displays 10 adjacent frames and shows the normal mode of bond bending (v_2). The two hydrogens can be seen to move towards each other (hence the bend), although their trajectories are slightly curved given the effects of rotation; this is discussed further later.

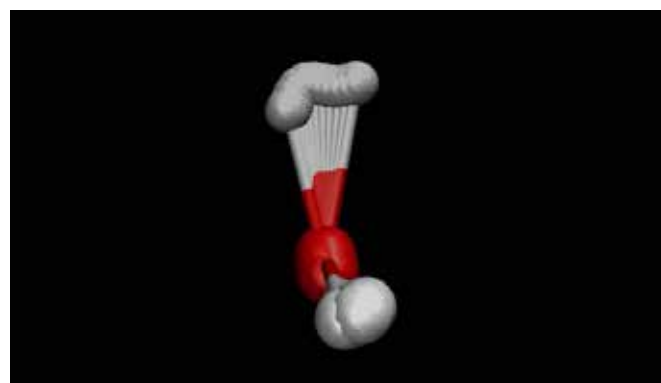
This image also shows a feature that is common to many of these images: the oxygen atoms move much less than the hydrogens do. I believe there are two reasons for this. Firstly, the oxygen atom has a much greater mass than both hydrogen atoms put together and so it need not move nearly as quickly away from the hydrogens to conserve momentum. Secondly, the movements of the oxygen atoms are smaller than those of the hydrogen atoms because they are more massive and thus have greater inertia. They are therefore 'reluctant' to accelerate.



The oxygen need not move as quickly in opposition to the hydrogens (to conserve momentum) as its mass is greater. In addition, it has greater inertia. Its overall periodic movement is thus smaller.

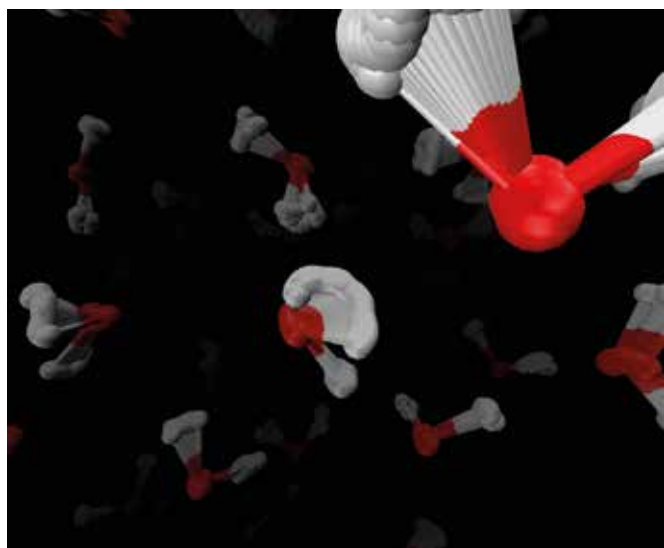
ROTATION

This movement is, once again, not a normal mode but nevertheless important for examining the trajectories of the each atom through space.



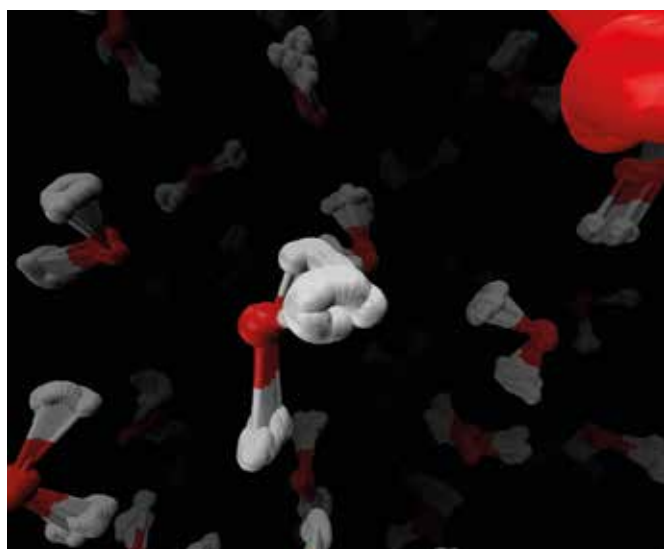
The above image (page 5) is a display of what was previously referred to as 'twisting': rotation about the principal axis of the water molecule. The camera angle provided displays well the movement of one bond in the twisting motion, which is an important factor in the hydrogens' trajectory. If this were the only motion acting on the hydrogens, they would pass back and forth along the same simple arced path. However, it is the combination of bending and rotation that gives rise to the most interesting patterns.

THE COMBINATION OF BENDING AND ROTATION



A common feature of the hydrogen trajectories that I have observed is shown in the image above, which is an extension of the first image shown immediately under 'Bending'. The hydrogen atom in the centre of the frame is seen to follow an arced trajectory: eventually displaying a semicircle. As the bonds bend back to their outermost position, the molecule is rotating about its three axes. This rotation causes the hydrogen to be displaced from its starting position, even after the entire bend is completed. Rotation in three dimensions and the bending together cause this semicircular pattern. The atom is in fact travelling towards the viewer (spiralling, if you will) but this is not well displayed in this image.

The photo below displays hydrogen spiralling (as I have named it) more clearly:

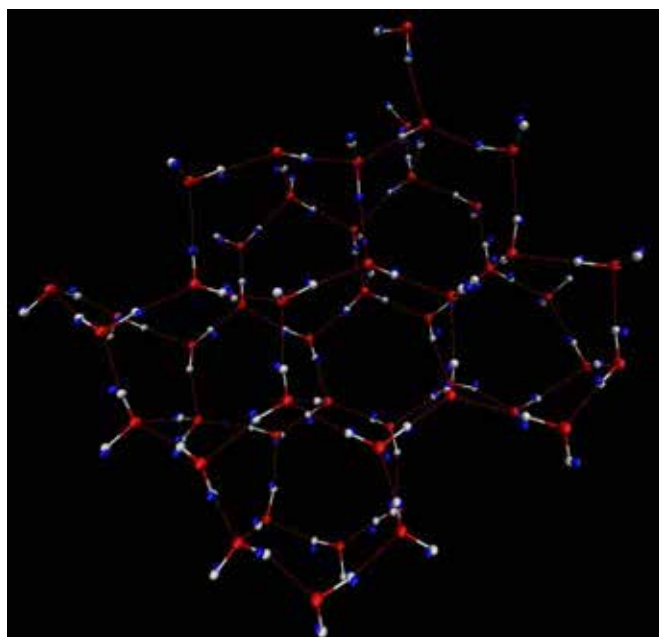


GOING QUANTUM

It is not the case (in the real world) that the locations of each atom are perfectly known. The two sources of quantum effects for water molecules are quantum dynamics and the quantum Boltzmann distribution. Although unproven, it is thought by many Theoretical Chemists that the Quantum Dynamics 'wash out' at this scale and the only real source of quantum effects is the quantum Boltzmann distribution. Quantum delocalisation is the term used to describe the degree to which one cannot be sure of a particle's true location. The model at the centre of this research in the Theoretical Chemistry department at Cambridge is referred to as the centroid/planet model.

One atom, the centroid, is in place to display the centre of mass of an atom – where it is most likely to be found. Another atom, a planet, is then used to model the degree of delocalisation. The further the planet is found from its centroid, the more unsure we are of where the atom truly lies.

This model was not first suggested by the researchers with whom I worked – it was first suggested two years ago by another group. However, it has been found at Cambridge to be backed up by experimental data.



Above is shown one of the first simulations I made of this model. This is a simple ice cell, with only 48 molecules (two layers of 24) with hydrogen planets shown in dark blue and hydrogen bonds shown in red. The hydrogen bonds are particularly helpful with ice to display the hexagonal structure. At this point I noticed an interesting feature; when the oxygen planets were coloured red like the centroid oxygens, they could hardly be distinguished from their centroids. The planetary oxygens were essentially on top of the centroid oxygens, indicating virtually no delocalisation. We can put this down to the fact that the oxygen atom is far more massive than the hydrogen atoms and thus the gap between its energy levels is far smaller, leading to far more classical behaviour. It therefore turns out that even though an oxygen atom is generally considered to be a minuscule object, it still behaves reasonably classically. In the early models, I therefore omitted the planetary oxygens for the sake of clarity.



The following links to a video showing the above in motion:

<https://youtu.be/Y8HiGV9ATZo>

I then went on to tackle liquid water (300 Kelvin – approximately room temperature) and the results are shown below.

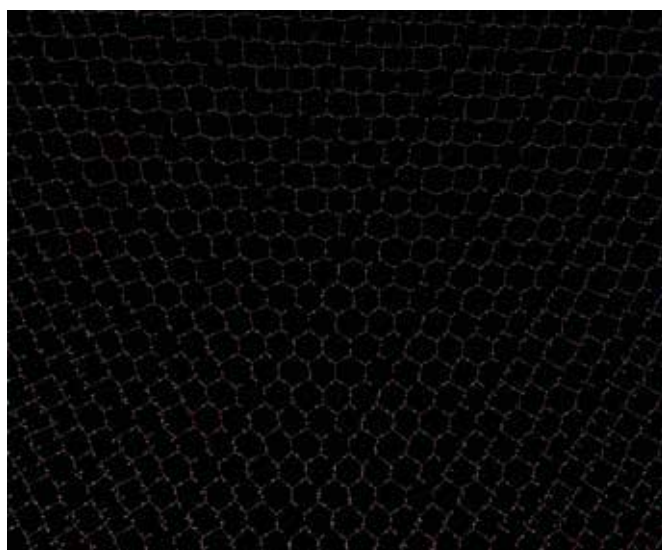
<https://youtu.be/kjWuxOM7rxQ>

elinked to below

<https://youtu.be/4kGzQV4Rc5g>

EXTENDING THE UNIT CELL

Below is an example of a major problem I experienced in VMD:



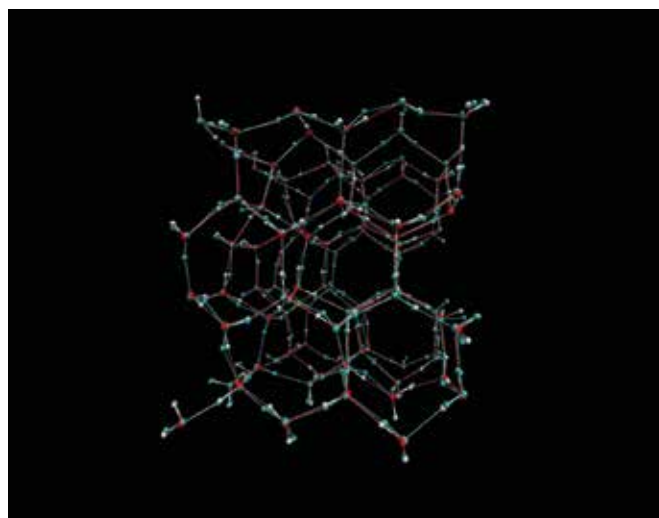
This is a model I produced of a much larger sheet of ice – only one molecule thick to best display the hexagonal structure. Using the ‘periodic boundary conditions’ in-built in VMD, the small cell of ice can be expanded and made arbitrarily large in 3 dimensions (although here it has only been extended in 2 dimensions to produce a sheet). The problem is that, upon close inspection, it can be seen that there are long lines of blackness where no hydrogen bonds are drawn. For whatever reason, VMD refused to draw hydrogen bonds between each replicated unit cell.

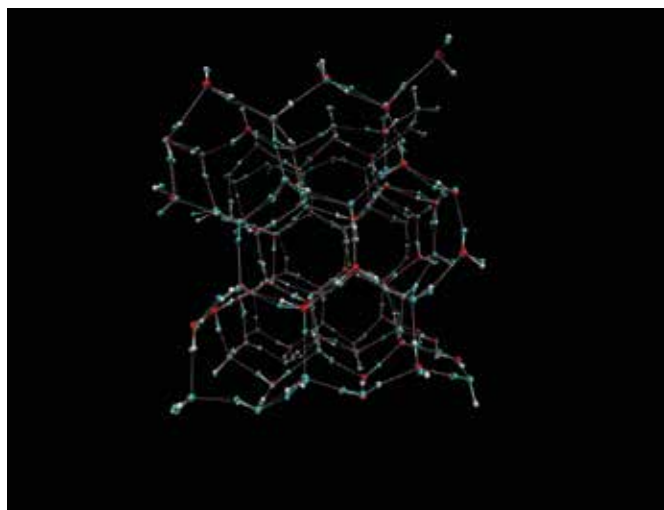
I realised the only way to resolve this, for both water and ice, was to change the raw files VMD was using (pdb files – protein database files). This was not a task that could be done by hand – some of the files I used have up to 2,500,000 lines of program. It therefore required a computer to go through and make these changes. It was also suggested to me that, in order to both remain loyal to the model and to aid visualisation, the planets should be shown on all three atoms and then joined by bonds to form ‘molecular planets’.

The above shows about 100 lines of the Java program I produced, which in total contained over 900 lines.

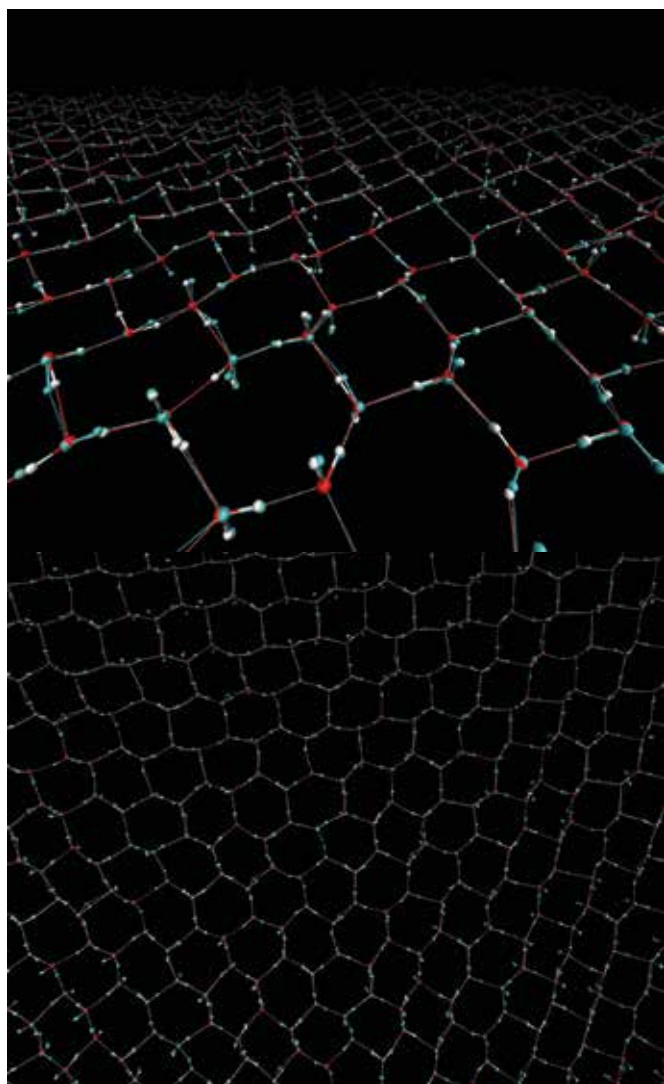
MOLECULAR PLANTS

Below are shown some of the results of the program on the ice model:





The above shows a simple cell of ice with the molecular planets displayed in light blue and the centroids in red and white (oxygens and hydrogens respectively). Hydrogens bonds are drawn in red and light blue between the centroids and planets respectively.



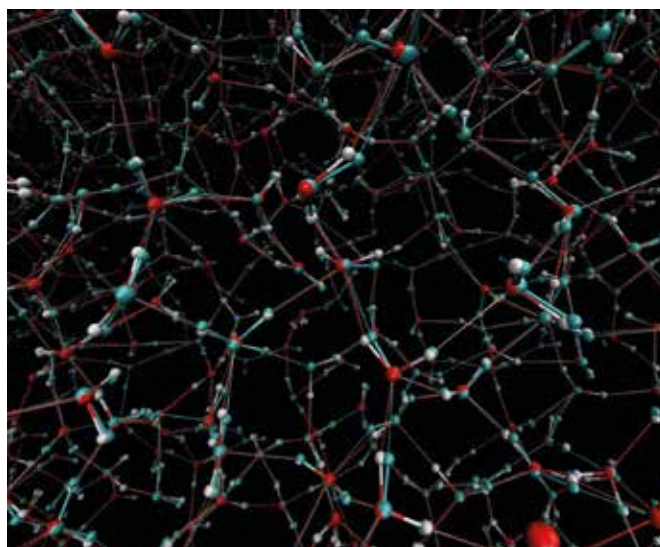
These show a sheet of ice one atom thick. Thanks to the Java program, we can now see that there are no breaks in the hydrogen bond pattern.

The corresponding videos can be viewed with the following links:

<https://youtu.be/htesRvTPrGU>

<https://youtu.be/YnOYuNuWTpk>

The results were similarly successful for water:



View the corresponding video here:

https://youtu.be/sZ64_tzTUIU

Both the image and video show each water molecule in an approximately tetrahedral arrangement, with each molecule forming two hydrogen bonds and receiving two more. The tetrahedral arrangement is formed as this is the lowest energy arrangement for any atom or molecule forming four bonds to other atoms or molecules. Tetrahedrons result in the least electron-electron repulsion and thus give the optimal, lowest energy arrangement.

I believe with the molecular planets idea and the continuous hydrogen bonding patterns throughout the structures, we have reached an optimal visualisation of these models.

CONCLUSION

The visualisation of models has become an important part of the scientific process, particularly after the advent of computers. Visualisations are key both for exploring new ideas and sharing old ones. Without images and videos, it would be very difficult to describe in a lecture theatre or in a classroom the exact nature of the normal modes of water. It would be even more difficult to describe the novel centroid/planet model explained here. I hope I have convinced you of the need and usefulness of these visualisations for both the development and communication of ideas. The models presented here are not perfect; it is integral to the scientific process that theoretical models are continuously refined to remain loyal to the experimental data and that absolute truth does not really exist in the real world. It is therefore my hope that these visualisations will aid the development of the next, more accurate model.



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Should social inequality in the UK be tackled and, if so how?

Vithushan Sivanathan

It is undeniable that inequality, in many different forms, exists in the UK. Inequality is defined simply as 'difference in size, degree, circumstances' (Oxford Dictionaries, 2017). There may be inequality with respect to income, wealth, race, gender, etc., but they all contribute to increasing social inequality. Income inequality, for example, in the UK is the seventh largest in the world, ahead of countries like France and Germany. Households in the bottom 10% have a net income of £9,644 whilst the top 10% have net incomes of almost nine times that, with £83,875 (Equality Trust UK, 2017). The gender pay gap is at an indefensible 13.9%, according to the Fawcett Society; racial inequality is becoming increasingly entrenched, with black graduates earning 23% less than their white counterparts (The Guardian, 2016); those from wealthier backgrounds are 18 times more likely to go to university than those from poorer ones (BBC, 2017).

So, having established that there are clear disparities in the distribution of opportunities and rewards among UK citizens, it may seem that the first question to be answered is 'How can we fix this problem?' However, some argue that the question should in fact be 'Should we fix this problem?' or even 'Is this a problem at all?' Those who hold the view that the government need not see the eradication of inequality as an objective present various theories to support their view which I will discuss and consider. Ultimately, I find their arguments unconvincing and I outline why I believe the inequality prevalent in our society cannot be justified.

I then come on to the second, and harder, part of my question, which is 'how?' – how should we go about solving social inequality? Each and every advanced society suffers from inequality. Attempts by Marxists in the 20th Century to create a society based on absolute equality failed feebly. Clearly then, there is no silver bullet to solve this problem. The proposals I make may be seen as radical, idealistic or even naïve and I acknowledge these concerns and realise the difficulties that my proposals would face if ever attempts were made to pass them into law. But this is no reason for me to not put them forward at all. I put them forward because I believe they are the best ways to tackle the problem in hand and I am unbothered by criticisms that they are naïve or idealist for, even if they are, I see no harm in being aspirational. The inequality I seek to tackle will not be gone in the near future, but that is no reason to not strive for change in our society. If my suggestions are deemed unpalatable at the moment then so be it, but if we aspire to and work towards the vision of a fairer and more just world, brought about by my proposals, then we may have a chance of seeing that vision become reality.

In a speech in 2013, then London Mayor Boris Johnson (now Foreign Secretary) proclaimed that 'inequality is essential for the spirit of envy'. Critics may argue that this is easily said from a man of privilege, but neoliberal ideas like this have, over the last forty years, become part of a global consensus, adopted first by Thatcher and Reagan in the 1980s

and then embraced by successive administrations. At the heart of neoliberalism is, like all individualist philosophies, the belief that humans are rational, self-interested and self-reliant: society, therefore, is nothing more than a collection of individuals, self-seeking and self-sufficient. This was famously encapsulated by Margaret Thatcher's assertion that '*... there is no such thing as society. There are individual men and women, and there are families.*' Such an egoistical view of human nature leads classical liberals to believe that negative freedom (the removal of constraints on the individual) combined with a minimal state (which is present only to maintain order and has no right to encroach on the liberties of its citizens) will lead to the most optimal and just society. This theory is applied to the market.

Neoliberals draw on the ideas of Adam Smith, who argued in his book 'The Wealth of Nations' (1776), that the market is regulated by the '*invisible hand*'. The forces of supply and demand ensure that resources are distributed efficiently and that the market remains in equilibrium. Competition within the market will ensure that businesses have a motivation to maximise their efficiency and productivity, contributing not only to increased profits for businesses, but also lower prices for the consumer. The unrestrained pursuit of profit and wealth creation is argued to benefit all. This, however, happens only if the market is free from government intervention – the market is, in their eyes, superior to government. Attempts to introduce any form of planning, regulation or bureaucracy in the market sap innovation, enterprise and efficiency. Friedrich von Hayek stated that the complexities of the market are beyond the understanding and capacity of politicians to handle – any attempt to meddle with market forces (through manipulation of interest rates, introduction of minimum/maximum price schemes, welfare benefits) will distort the natural and fair operation of the price mechanism. For this reason, the 1980s and 1990s were marked by tax cuts for the highest earners, privatisation of publicly owned institutions, reduction in welfare provision, etc. Market fundamentalists maintain that the price mechanism is able to solve all economic and social problems and, as the free market is the fairest way of distributing goods, then any inequality that occurs can be justified.

The free market is said to give all an equal chance to succeed or fail. One's social and economic position is determined by your own hard work and endeavour, talents and innovations – those willing to work are rewarded with wealth, whilst those who find themselves at the bottom are there only through their own personal failure. Bluntly, the free market gives us what we are due and our circumstances are deserved. This argument echoes the assertions made by those who believe in a meritocratic society. Inequality of social position, income and wealth are all a natural consequence of the inherent inequality within people themselves. Further to this, inequality is argued to be helpful in motivating individuals to better their own situations (which takes us back to the initial Boris Johnson quote). The promise of extra reward as a result of working harder will lead to higher national



output and, if the trickle-down theory is to be believed, will benefit all. Inequality is therefore not only inevitable, but also desirable, as it can aid social mobility.

However, I profoundly disagree with much of the reasoning above and the end conclusion it forms. I am first sceptical of classical liberalism's view of human nature. I find it hard to believe that all humans are merely selfish, self-interested creatures with no sense of social belonging. A world in which humans each pursue their own goals and aspirations, following their own personal morality, irrespective of all others, like individual atoms, is neither real nor one we should aspire to.

Moreover, it is wrong to suggest that we are solely defined by our own inherent, natural attributes. We are not born the person that we turn out to be. Though our genetic makeup may inform our character and behaviour, our nature is *nurtured* by the society we grow up in and the experiences we have in it. I believe that I would be a different person had I been born and raised in Sri Lanka, where my family originates from. Religion would more strongly inform my views and thinking due to the fact that my faith, Hinduism, would play a much larger role in my upbringing – through my education, culture, daily life, etc. In addition, I would likely be more studious and hard-working, due to the fact that in Asian society, a much greater emphasis is placed on the importance of education, due to widespread poverty, whereas in Britain I would argue there is less of an urgency surrounding education. If one's environment moulds one's character, outlook, personality, etc., then it follows that humans are not distinct from the society in which they live – the individual and society are one.

Furthermore, the individual has, I believe, social responsibility for their own community. How can it be that individuals owe society nothing and should be free to be self-serving creatures? Individuals enjoy the benefits that society brings: guarantee of individual liberties and freedom, protection from invasion, maintenance of social order (without which we would slip into the chaos of the 'state of nature'), the means by which to develop one's skills etc. In return for the benefits that society provides, surely we have a duty to act in the interests of the community. In fact, I believe that at the heart of human nature is a collectivist core – we have an innate desire to pursue the goals of the group with which we identify. Individuals do not only work for themselves in competition against others; they recognise the mutual benefits that can be gained if they cooperate with their community. I certainly do not advocate the complete eradication of competition among individuals in pursuit of personal, material wealth, for this increases utility among individuals... but a balance must be struck between this and a commitment to the welfare and wellbeing and utility of society. Extreme egoistical individualism threatens social cohesion and it must be restrained by a sense of social responsibility.

Therefore, the unregulated and unrestrained free market, underpinned by this egoistical individualism, threatens cohesion through its inevitable creation of inequalities. Though it is undeniable that a free market is more efficient than one that is centrally planned, I do not accept market fundamentalists' argument that the economic inequality created is justified or beneficial. Fundamentalists argue that the market provides all with an equal opportunity to succeed, but this is simply not true. Let us imagine that there was a point when the idea of a free market had just been conceived and was just about to be implemented. Let us say also that at this point, all individuals are completely equal in all ways except merit (i.e. ability

to work hard, talent, etc.). As this generation of individuals operates within the free market, inequalities will emerge, as intended, due to the natural inequalities in merit. This, as a pure meritocracy, can be justified. However, the next generation of individuals do not enter the market on an equal footing, for some have inherited the wealth of previous individuals and some have inherited the poverty of previous individuals. In this way, some are advantaged and some disadvantaged, not on the basis of merit but on the basis of inherited wealth and privilege. In this way, inequality becomes larger and larger, as initial inequalities are multiplied and distorted by social privilege and poverty being passed down from each generation. Some may argue that those who have inherited wealth will have also inherited the genes of their wealthy parents (who made their wealth based on merit alone) and so they are bound to succeed also, irrespective of inherited wealth. However, a study in Sweden seems to suggest otherwise:

'Researchers have looked at the data from a group of Swedish children who were adopted between the 1950s and 1970s. They analysed what link there was between these adopted children's wealth when they were adults and the wealth of both their genetic and adopted parents. They found that the children's wealth in their 40s is strongly linked to their adopted parent's wealth and weakly linked to their genetic parents' wealth. Wealthy parents who adopted raised children then became wealthier than other children. This suggests that not only does wealth get passed on from parents to children, but that this is not mainly due to inheritance of skills or talents, but instead through environmental factors (e.g. how a child is raised) and direct transfers of wealth.' (Equality Trust UK, 2015)

In this way, social inequality is no longer justified by free market liberals as there is no equality of opportunity. Furthermore, this inequality is no longer beneficial either. It is leading to social exclusion, whereby the poorest in society are being denied the opportunity to better themselves due to their inability to access resources that are readily available to those born into wealthy families. Through neoclassical assertions that the free market is fair, those from privileged backgrounds have kid themselves that they have acquired their wealth through merit alone, ignoring the many advantages such as high quality education, inherited property and assets and superior social status that have more than helped them to succeed.

I do accept that a certain level of inequality is justified and needed in society but only to the extent to which it benefits the most socially disadvantaged. This idea was developed by John Rawls in his 'A Theory of Justice'. His second principle of justice, made up of the 'Difference Principle' and the 'Equal Opportunity Principle', was that:

'Social and economic inequalities are to be arranged so that (a) offices and positions must be open to everyone under conditions of fair equality of opportunity (b) they are to be of the greatest benefit to the least-advantaged members of society...' (John Rawls, 1971)

The idea of the 'Difference Principle' is one that I agree with. Though some have interpreted Rawls' idea as being apologetic to the effects of capitalism and morally permitting the gap in income between the richest and the poorest (as long as it was the best possible distribution



for the poorest), I believe that this idea is much more egalitarian than critics give credit. This principle recognises that in our society, where there are natural inequalities in talent and abilities, if those with talent are free to utilise their natural advantages they can bring about benefits for society as a whole, even when inequalities arise as a result. The example Rawls used was the comparison between a doctor and a grocer: the inequality in income between a doctor and a grocer is justified as it benefits not only the doctor but also the grocer, for he now has access to medical care. Though I agree with this reasoning, it is based on the assumption that all have an equal opportunity to become a doctor which, as mentioned earlier, is not true. Furthermore, the social inequality present in society is so huge and so entrenched that it no longer benefits those at the bottom. Therefore, to answer the first part of my initial question, 'Should social inequality be tackled?' I argue we should tackle the social inequality that exists in the UK because it is unjustifiable.

'How should we tackle social inequality?' is the next part of my question. Most see the promotion of either equality of opportunity, which I have discussed, or equality of outcome, as put forward by socialists, as the path that can be taken.

Equality of outcome requires that people are 'treated equally...by society in terms of their rewards and material circumstances' (Heywood, 2014). However, though I am strongly in favour of a more egalitarian society, I am opposed to this absolute social equality. This is because pure equality of outcome is both unattractive and harmful. Aggressive taxation to achieve equal results stifles innovation, progress and growth and is ultimately unfair. Those who work hard should be rewarded for their efforts. The endeavours of these people contribute to the improvement of society, e.g. technological developments making people's lives easier, advancement in medicine resulting in increased life expectancy, etc. If the incentives to work hard are removed (extra rewards) then society will be worse off for it. The problem of present inequality stems not from wealth creation by the most talented, but from inequalities being handed down from generation to generation, creating barriers to true equality of opportunity... so therefore it seems we should work towards removing those obstacles to create the fairest society instead of pursuing policies to achieve equal outcomes. But how can we achieve equality of opportunity if there is no form of redistribution so that, at birth, all have an equal opportunity to succeed. If we follow only the path of equality of opportunity, social inequality will go unsolved for the justifiable inequality that arises will create inequality of opportunity and then unjustifiable social inequality. This course of events is unescapable. Pursuing either equality of opportunity or outcome will not tackle social inequality effectively. To me it is clear that a path that somehow combines both of the previous ideas should be followed. This path, I think, can be found when exploring competing theories of freedom and liberty.

When explaining classical liberal theory earlier, I briefly mentioned the idea of negative freedom - '*a free man is he that in those things which by his strength and will he is able to do is not hindered to do what he hath the will to do*' (Hobbes, 1651). In other words, negative freedom is the removal of external constraints on the individual, either legal or physical, created by other individuals. In effect, you are giving the individual freedom of choice - choice to practise a certain faith, choice to set up a business and pursue profit or choice to have fish and chips on a Friday night. This theory of liberty is applied to

the market in the form of economic liberalism as discussed. However, I have argued that economic liberalism leads to social exclusion, denial of opportunities for the poor and the creation of obstacles to social mobility. In this way, are people really free? Do they really possess personal liberty? True, there are no explicit laws or barriers denying the most socially disadvantaged the opportunity to become successful and so a classical liberal would therefore argue that they possess liberty. And yet those disadvantaged are, despite this, being denied those opportunities - the doors to success are shut. The only door open is marked 'the status quo'. What sort of liberty is this? Even if negative liberty has been granted on paper, in reality, it means very little to those at the bottom because their freedom of choice and opportunity is limited. Here lies the crux as to why social inequality has gone unsolved.

Unjustifiable social inequality has been brought about due to inequality of true freedom and liberty. Freedom and liberty, since the neoliberal governments of the 1980s, have been defined as the absence of constraints on the individual, and as long as these are removed, whatever happens in society is just, for all are free. I do not agree with this. Liberty is not merely the removal of external constraints on the individual - liberty, in my view, is achieved when individuals have the ability and means to fulfil their ambitions and potential. This may be categorized as a belief in 'positive freedom'. Positive freedom is '*not freedom from, but freedom to...*' (Berlin, 1958). Isaiah Berlin goes on to define positive freedom as the ability to be one's own '*master*'. This can be achieved if the individual is able to 'develop skills and talents, broaden his or her understanding, and gain fulfilment.' (Heywood, 2014). Individuals are most free when they have the means to achieve self-realisation - this is when all the doors are open. This is the path to take to solve social inequality.

A society, which considers the individual free when they have the means to develop their abilities, will lead to the removal of unjustified, inherited inequality, for this inequality encroaches on one's positive liberty. The promotion of positive freedom holds the key to eradicating unwarranted inequality. If all individuals have positive freedom, they will be able to fulfil their potential and inequalities that arise will be justifiable for they only reflect the inequality in potential and skill and talent within individuals themselves. This may seem similar to pursuing equal opportunities, but the difference is that the promotion of positive freedom allows for a level of redistribution in order that the inequalities that arise do not become entrenched, which is not possible in following equality of opportunity. I still uphold the view that free market economics, which is overseen and managed by a government willing to step in when the market fails, is the most efficient way of distributing resources. However, the inegalitarian outcomes of the market must be tempered by a commitment to social justice in order to maintain positive freedom among individuals.

The government must introduce measures to cushion the blow that those who are landed with disadvantages receive, and they must also work to break the closed loop that ensures that the rich unfairly entrench their privilege and wealth. Only then are we equally distributing opportunities and then mitigating the unequal outcomes that they produce so that positive freedom is preserved. There are several ways in which the above can be done but I would argue that reforms to education and taxation of wealth are among the best.



EDUCATION

Education is viewed as the key process for making sure that all have an equal chance of social mobility. There is no better way to promote the freedom to do something than through education – it provides people with knowledge, skills and independence, which, in recent years, have become vital assets in securing a job, for 80% of GDP is now produced by the skills based, tertiary sector of the UK economy. In theory, education should provide the poorest with an opportunity to secure well paying, professional jobs, which will eventually lead to the reduction of social inequality. However, the evidence suggests that the UK's education system has facilitated the increasing entrenchment of inequalities. Children from wealthy backgrounds, who were less able at age 5, are 35% more likely to become high earners as adults than children who scored more highly for cognitive development at age 5 but came from poor backgrounds (The Social Mobility & Child Poverty Commission, 2015). It has been shown that wealthy families construct a 'glass floor' for their children through 'hoarding' of educational opportunities. On the other side of the spectrum, it has been proven that low socioeconomic status contributes to low educational attainment: this then leads to poverty rooting itself further, making it even harder for the next generation to escape it. Education should be part of the solution of social inequality, not part of the problem. Right now, it is amplifying the pre-existing advantages and disadvantages of families. To solve social inequality, we must solve the educational inequality in the system. Radical governmental reform is needed to bring about increased equity in schooling coupled with efforts to raise standards. The combination of academic excellence and equity will ensure that all children are truly given an equal opportunity to succeed in their adult life.

The education system needs to first protect children from the disadvantages they inherit from their parents in their early years. The first few years of a child's life are a vital period for brain development – the environment a child grows up in and the quality of care it receives impacts on its long term trajectories as an adult. Social inequality affects the quality of life of parents – it can lead to mental health problems, stress and substance abuse, which will obviously contribute to a poor environment for child development. In the UK, 2.3 million children live in relative poverty (Pickett & Vanderbloemen, 2015) and many will have been exposed to risk factors such as those mentioned above. Further to this, income inequality, in extreme cases, may lead to child maltreatment – children living in low income families are more likely to experience family conflict, violence and abuse (ibid). All these factors contribute to an environment, for low income families, that is neither nurturing nor conducive for cognitive development, which will have a huge impact on future educational ability. In contrast, the environments that children from professional families grow up in are more stimulating and the quality of care the child receives is better. An American study has found that children from wealthier, professional backgrounds have a richer vocabulary than their poorer counterparts as shown in the figure. Furthermore, their job security and manageable working hours will leave plenty of time for family life: their children gain a head start in learning simply because of the safe, social and loving environment that they live in.

Family Status	Words heard per hour	Words heard in a 100 hour week	Words heard in a 5,200 hour year	Words heard in 4 years
Welfare	616	62,000	3 million	13 million
Working class	1,251	125,000	6 million	26 million
Professional	2,153	215,000	11 million	45 million

Figure 11: Children from families receiving welfare benefits and in working class families hear fewer words than children in professional families. (Heckman, 2011; Hart and Risley, 1995)

I do not believe that it is fair for the life chances and opportunities of to be impacted so early in their childhood. Attempts must be made to create and subsidise the environment that a child needs to fully develop so that their future life is not sabotaged by the circumstances of their birth. Universal provision of family services and expansion of parental leave will ensure that families are able to focus on nurturing their child. Reform of nurseries and early learning centres to increase the quality of care will counter the negative effects of the home environment.

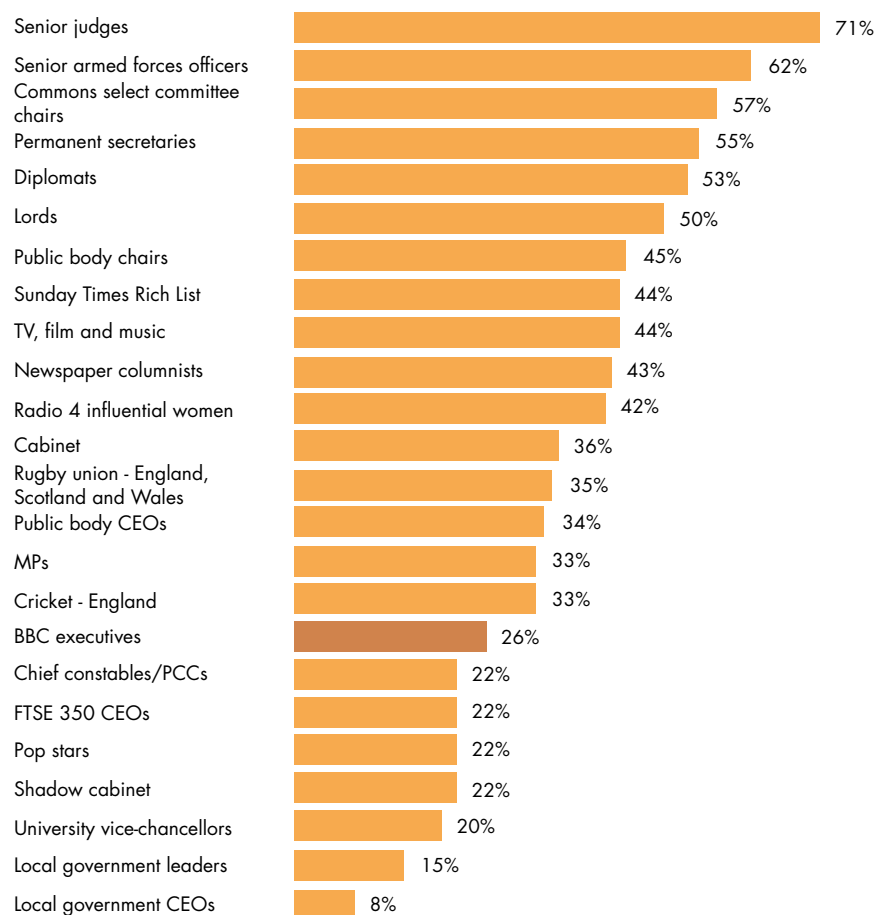
Having ensured that children are not set back by socioeconomic circumstances from birth, the government needs to combat the lack of equal opportunities in the secondary school system. I mentioned before that richer families provide their children with a 'glass floor' and educational resources and opportunities are 'hoarded'. This, I believe, can be explained by the existence of private schooling. The presence of independent schools has long been the political taboo or 'elephant in the room' but we can no longer ignore the issue. Private schools unfairly advantage those who attend them and, in doing so, multiply social inequality in society.

Only 7% of the UK population attends private school and yet they are heavily represented in top professions, as demonstrated by the figure.

Clearly, private schools dominate the top jobs in Britain and by doing so have brought about an elitist society. Indeed a study by the National Centre for Social Research warned how British private schools were entrenching a form of 'social apartheid' and promoting a ruling class drawn from a 'segregated elite'. Those lucky enough to attend private schools have access to the best teachers (who are more likely to have postgraduate qualifications compared with their state counterparts), are taught in smaller classes, enjoy better facilities, etc., and the main reason for them having these advantages is because of their parents' pre-existing wealth. Private schools have meant that the opportunity to succeed has become concentrated in the hands of the few and has been closed off to the socially disadvantaged. As the best resources are taken by private schools, the state sector languishes and standards in those schools dip, disadvantaging already disadvantaged students. As I argued earlier, social inequality is only justified if all have had an equal opportunity to succeed. It follows therefore that to ensure equal opportunity, we must first work to phase out private schooling.



% privately educated



SOURCE: SOCIAL MOBILITY AND CHILD POVERTY COMMISSION

There are perfectly legitimate reasons for a parent to send their child to a private school – parents naturally want to give their child the best chance of succeeding in life. They feel, quite rightly, that their aspirations for their child will be realised if they receive an excellent education and so are prepared to pay the fees. Some therefore argue that the abolition of private schools would lead to a dumbing down of educational standards. However, I argue that we would in fact see rising standards in state schools as a result. If rich families no longer have the option to opt-out of the state system, they will be compelled to invest in the state sector 'emotionally, physically, politically and financially' (Huffington Post, 2012), thereby forcing standards in those schools to rise. Furthermore, the redistribution of educational resources, once held by private schools, will ensure that all have access to them.

There is precedent for the abolition of fee paying schools. Finland, in the 1970s, abolished all private and selective schools in favour of universal comprehensive education.

'Since the publication of the first PISA results in 2001, Finland is now seen as a major international leader in education (OECD, 2010). It has consistently ranked in the very top tier of countries in all PISA assessments over the past decade, and its performance has been especially notable for its remarkable consistency across schools. No other country has so little variation in outcomes between schools, and the gap within schools between the top and bottom-

achieving students is extraordinarily modest as well. Finnish schools seem to serve all students well, regardless of family background or socio-economic status.' (OECD, 2010)

The success of Finland validates my recommendation for the abolition of private schools. However, having achieved equity in schooling, there must be a drive to increase academic performances and standards in British schools or else productivity, innovation and the economy in the long run will suffer, compared with other countries. Though private schools have concentrated opportunity, their methods of increasing educational attainment can be used as a blueprint on which to raise academic standards in the state sector. Combining equity and excellence is the way in which to provide all children with the best and equal chance to succeed. Recently though, some have argued that a system different to both private and comprehensive schooling will promote the values of social justice and equal opportunity.

Having become Prime Minister in 2016, Theresa May breathed political life back into *grammar schools*. The Labour government of 1997 banned the creation of new grammar schools in England. Mrs May argues, however, that grammar schools ensure that the '*most academically gifted children get the specialist support to fulfil their potential regardless of their family income or background*' (Telegraph, 2017). There is no denying that those who attend grammar schools achieve success – 96.7% of pupils attending grammar schools in 2014/15 achieved 5+ A*-C grades at GCSE, compared with 56.7%



at comprehensives (Parliament UK, 2017). However, there are many problems with regards to grammar schools that discredit them as a viable education system for a Britain looking to be more socially mobile.

First of all, evidence has clearly shown that grammar schools have failed to admit enough of those from low socioeconomic backgrounds. Eligibility for free school meals is an indicator of low income families and less than 3% of students in grammar schools were eligible (FullFact, 2017). This is largely because grammar schools are hijacked by those parents who can afford to tutor their children for the 11+ exam, which all entrants need to pass. They are detrimental to social mobility. Furthermore, it is completely unfair to separate children into 'winners and losers' at the tender age of ten or eleven. Those who win a place, no doubt through tutoring, do well in life but those who were rejected, on the grounds of not being academically bright enough, see their chances of success significantly reduced.

'There is repeated evidence that any appearance of advantage for those attending selective schools is outweighed by the disadvantage for those who do not' (Professor Stephen Gorard, Durham University). This is precisely the point. If we returned back to a situation similar to the 1960s whereby a quarter of all students entered grammar schools, we would be making steps backwards in terms of social justice, inclusion and equal opportunities. Grammar schools are no better than independent schools in their effect on society.

Therefore, I revert back to my view that the abolition of private schools is the only way forward in bringing about a more equitable society. Education has the capacity to regulate the relation between an individual's initial social status and the one that they end up in. We need to work to create an education system that brings about upward mobility by providing all with an equal opportunity to succeed. We must cushion the blow of inherited low socioeconomic status on the next generation and achieve an equal playing field to succeed through an equitable distribution of educational resources and opportunities in order to advance social justice and positive freedom.

TAXATION

I argued earlier that social inequality is no longer justifiable due to the fact that the unequal outcomes of the previous generation are inherited, which leaves some, in the current generation, advantaged and some disadvantaged. Education, as I explained, can help to mitigate the socioeconomic handicaps that the poorest are left with. Taxation, on the other hand, has the ability to fairly curb the excessive socioeconomic privileges that the richest receive, which will help to break the elite's stranglehold on opportunity. I do not believe that an aggressive tax and spend culture is a viable route, as it leads to many unintended consequences such as disincentives, high consumer prices (leading to inflation), capital flight, etc. Therefore, a balance must be found between increased equity and lack of economic distortion. I believe that the best way to do this is through a form of inheritance tax on property.

John Locke, the great proponent of individual property rights, put forward his view that humans have a moral justification to own property in his book *'The Second Treatise'*. He argued, first, that property acquisition is just, for, without it, humans would not be able to survive. The 'fundamental law of nature' is the preservation of mankind and so if this is to be upheld, man must be able to take things in order to survive. Second, he justifies private property using his 'labour-mixing argument' – those who labour on a plot of land are entitled to keep it as (a) you own your own labour for you own your body and (b) by 'mixing' your labour with the land you add value to it which entitles you to appropriate it (Wolff, 1996). Even if we are to accept that there is justice in acquisition of property, there is no justice in the transfer of property to the next generation. Your children have no truly legitimate claim over the property that you yourself have 'mixed' your labour with. This problem is made worse by the fact that Locke based this theory on the proviso 'enough and as good' which stipulates that property may only be justly acquired if property is plentiful for all: Figure 3 below clearly shows that there has been a marked increase in the price of houses and Figure 4 demonstrates that the affordability of average housing has clearly diminished over the last three decades.

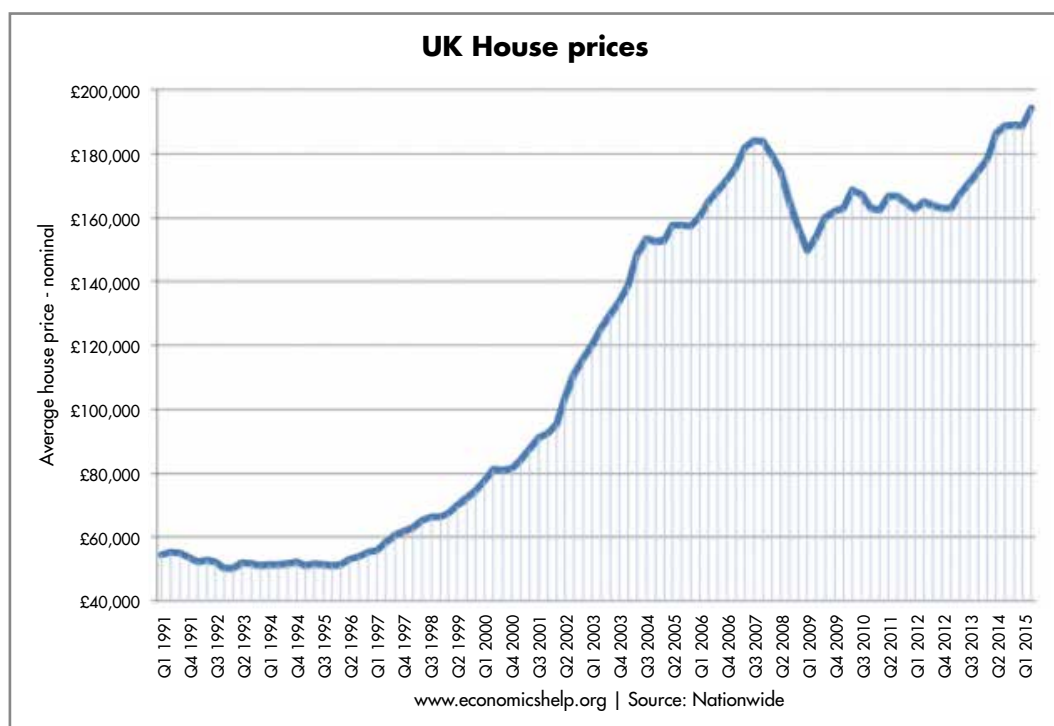


Figure 3



This can, in part, be attributed to a concentration of property among a wealthy elite. The transfer of property from one generation to the next perpetuates social inequality. 'Roughly £400bn presently tied up in homes owned by people aged 65 to 85 will be handed down to their children and grandchildren' (The Guardian). According to the Institute for Fiscal Studies (IFS), this inheritance will play a vital role 'in determining the lifetime economic resources of younger generations, with important implications for inequality...'. According to recent estimates, '90% of inherited wealth will go to just half the next generation'.

If the transfer of vast sums of wealth down the generations, and with it huge life advantages and opportunities compared to those with no private property, cannot be justified, then an inheritance tax is warranted. I do accept that there is a natural human desire to pass on your wealth and possessions to your children. I do not seek to outlaw it. However, the transfer of wealth is constructing barriers, to those with no inherited wealth, to accumulate wealth of their own then this is unjust.

Conservative notions of the magical healing powers that property has on society have, so far, discredited the idea of inheritance tax as a just way of dealing with social inequality. But if inherited wealth is leading to social exclusion and life chances are being determined by pre-existing wealth, then it is having the opposite effect on society. An inheritance tax should therefore be levied, but only one that meets these conditions: it should (a) be applied to estates valued in the millions of pounds, in order to change public perception that it is somehow a 'death tax' for all people and (b) be made progressive, rather than a flat rate, so that it becomes a fairer (and more palatable) way of redistributing wealth, promoting equal opportunities and ensuring positive freedom for all. Inheritance tax does

not discourage enterprise, destroy incentives or distort the market to the extent that income tax is argued to do. It is therefore a more optimal way of reducing social inequality.

I do believe it is time that politicians truly attempt to reduce the social inequality in society – too often have they vaguely alluded to or mentioned the idea of equal opportunities or social mobility merely to garner applause or produce a soundbite. The time for debating whether social inequality is a problem at all is over. The injustice it has created, and continues to create, is plain for all to see.

If we are to bring about a more just society, we must strike a balance between equal opportunities and outcomes through the promotion of positive freedom. I have explained just two ways in which this can be done. At the beginning of my piece, I acknowledged that what I am proposing is likely to be viewed as too radical. Indeed, the abolition of private schools will be met with fierce opposition, and politicians have been afraid to campaign for it out of fear of its electability. In addition, the success of conservatives in spinning tax on the transfer of wealth as a 'death tax' has meant that we have so far been unable to consider it. Nonetheless, I put forward these radical policy suggestions because the problem we face is radical in itself. Social inequality and its ramifications are detrimental to society's cohesion. Recently we have witnessed the emergence of a more divisive, isolationist world order. Although I am opposed to the ideas of Brexit and a Donald Trump presidency, I have great sympathy with the sense of dissatisfaction, injustice and desire for change that brought them about, which can be attributed to the effects and consequences of inequality. The time to act is now before we see the irreversible breakdown of society itself.

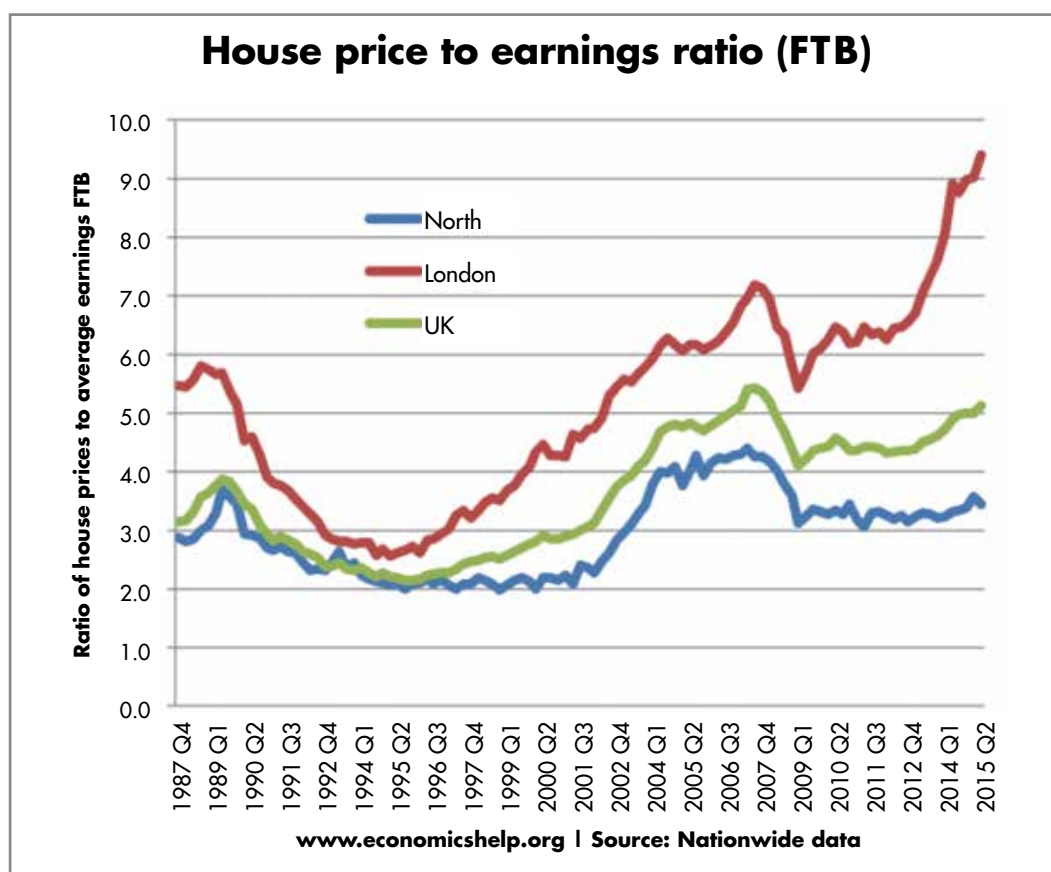


Figure 4



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Using open source science to find a cure for malaria: triazolopyrazine series

Ewen Ward, supervised by Dr Philippa Cranwell of the University of Reading



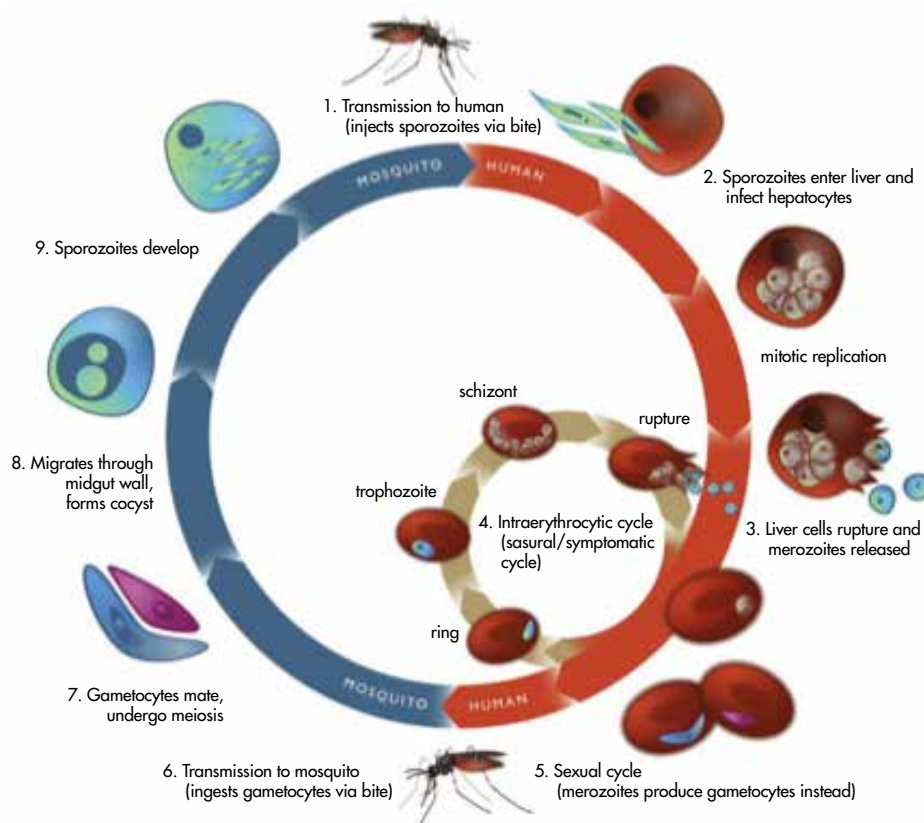
ABSTRACT

The overall aim of my project was to synthesise a compound, containing a triazolopyrazine core, that could potentially be used to combat malaria. The target molecule I would be working towards was suggested by the Open Source Malaria project, and is part of their triazolopyrazine series of compounds. In order to reach the final target molecule, I would be following a reaction pathway over multiple steps, each of which would have to be planned and executed with precision to ensure success.

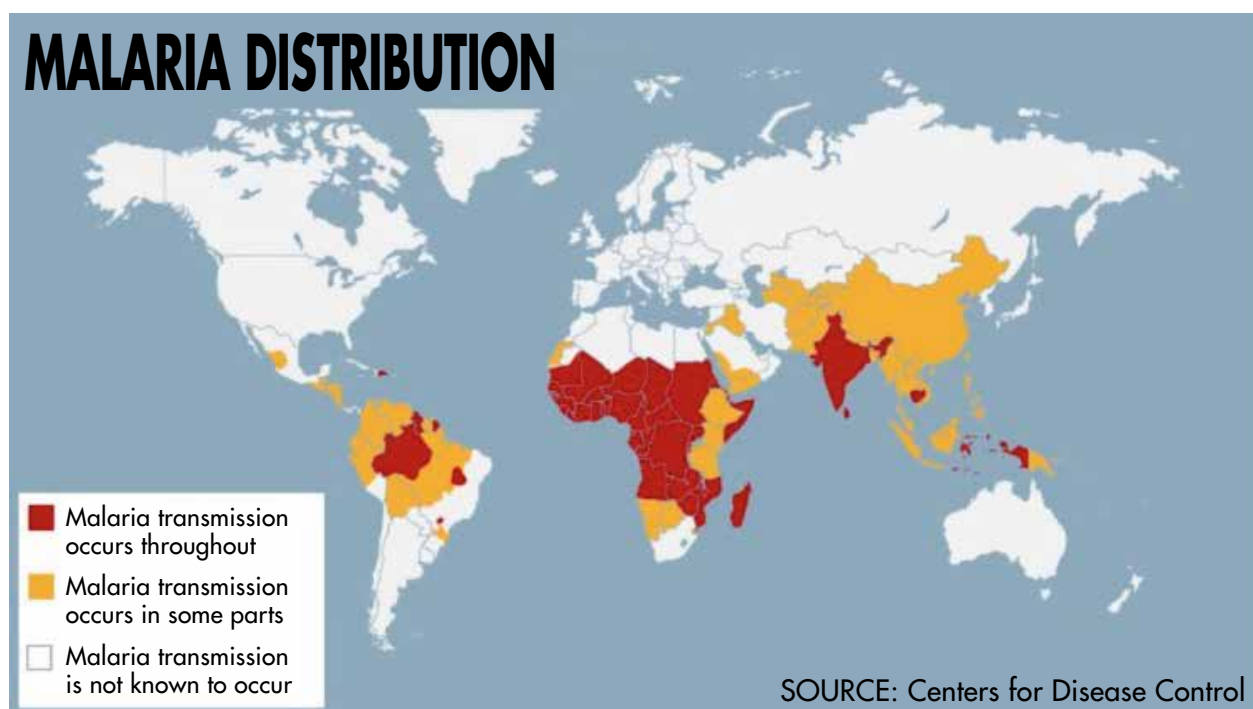
Since this was my first time being in a university laboratory, alongside documenting the progress and success of the reactions I will also discuss all of the new techniques and pieces of equipment I was introduced to, and used, during the project.

PROJECT BACKGROUND – MALARIA AND OPEN SOURCE MALARIA:

Malaria is a disease caused by the parasite *Plasmodium* (NHS, 2015), a protist with five malaria-causing species: *P. falciparum*, *P. vivax*, *P. ovale*, *P. malariae* and *P. knowlesi* (Wikipedia, 2014), of which *P. falciparum* causes the highest number of infections. Malaria is a very dangerous disease as if it is left untreated it can quickly become fatal; symptoms of the diseases include fever, headaches, vomiting, diarrhoea and muscle pains (NHS, 2015). A malaria infection also often brings with it numerous complications such as pneumonia, metabolic acidosis (low blood pH caused by excess acid in the blood), pulmonary edema (fluid build-up in lung tissue and airspace) and anemia (decrease in number of red blood cells/amount of haemoglobin) (Wikipedia, 2014).



The life cycle of the malaria parasite, showing how it develops and reproduces as it is transferred between humans and mosquitoes via bites



A map from April 2016 showing the distribution of malaria around the world, highlighting where the disease is widespread, not common and believed to not be present

The Plasmodium parasite infects people through mosquito bites. Female Anopheles mosquitoes are most well-known for spreading the disease, where the parasite is injected into people's bloodstream from the mosquito's saliva when being bitten (Wikipedia, 2014).

Malaria is currently active in over 100 countries and endangers nearly half of the world's population. According to the WHO, in 2015 there were 212 million malaria cases and an estimated 429 000 malaria deaths (World Health Organisation, 2016), demonstrating the devastating impact the disease is still having. Malaria is typically found in tropical countries where the climate for both the mosquitoes and parasite are favourable for breeding (Bretscher, 2008); the majority of infections are in sub-Saharan African countries where limited healthcare is also a major contributing factor.

Although there were estimated to be 429 000 deaths from malaria in 2015, progress has been made and since 2010 the malaria mortality rate has fallen 29% globally (Bretscher, 2008). There are currently two main preventative measures in place to combat the disease. Firstly, mosquito nets are widely used in combination with insecticides in homes to prevent people being bitten. While these are effective in stopping mosquito bites from taking place, they do not provide any solution once someone has been infected. Secondly, specific anti-malarial drugs can be used to treat the disease; however, resistance to the drugs is an ever-growing problem. Currently the most effective treatment against malaria is artemisinin-combination therapy (Wikipedia, 2014), where the drug artemisinin (which has comparatively low resistance) is used together with other anti-malarial drugs to fight the disease. This approach is effective as it decreases the chance of the parasite gaining resistance to both drugs at once.

The Open Source Malaria (OSM) project is an open science collaboration that brings together groups of scientists from around the world to synthesise and test potential compounds that have shown promise in combating malaria. It was set up at the University of

Sydney, Australia, in 2011 and has been working since to synthesise compounds released by GlaxoSmithKline (GSK) believed to have anti-malarial properties. The organisation, being an open science medium, expects that any research made by an OSM team-member is public and anybody is welcome to contribute either by doing research on their behalf, or by offering suggestions to improve work that has already taken place. This means that people all over the world can be simultaneously be working on the same project, improving the speed of the project's progress; moreover, efficiency is increased since work does not have to be repeated if all research is shared online.

Listed on their website are the six laws that OSM follow being an open source organisation and are a good representation of the open source work ethic (Open Source Malaria, 2014):

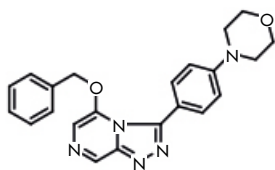
1. **First law:** All data are open, and all ideas are shared
2. **Second Law:** Anyone can take part at any level
3. **Third Law:** There will be no patents
4. **Fourth Law:** Suggestions are the best form of criticism
5. **Fifth Law:** Public discussion is much more valuable than private email
6. **Sixth Law:** An open project is bigger than, and is not owned by, any given lab

OSM is currently in its fourth series of potential molecules known as the triazolopyrazine series; triazolopyrazine refers to the two central rings, a pyrazine and triazole, found in each compound (ChemSpider, 2015).

Previous work on the first three series has been halted for various reasons, either due to certain characteristics making the work difficult and unfeasible (especially when there are many other compounds to try and synthesise) or that researchers not part of OSM were looking into that compound at the same time (Open Source Malaria, 2014).



For my project, I would be working on synthesising the substituted triazolopyrazine shown below:

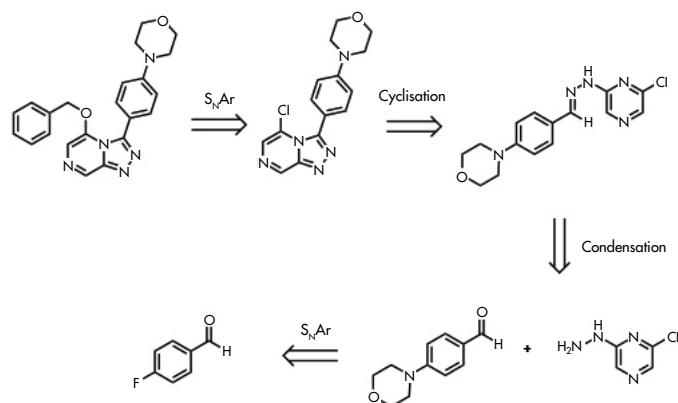


Before each reaction was started, a COSHH (Control of Substances Hazardous to Health) form was filled in, detailing all of the substances I would be using, what their hazards were and what precautions should be taken against them. Before each reaction, the mass/volume of each substance would be calculated, as well as defining a methodology for the reaction, in particular the order that the substances should be added to the round-bottomed flask. All the substances and apparatus needed for the reactions were available in the laboratory and all the reactions took place in a fume cupboard. Since most of the reactions I would be doing had not specifically been done before, it was not known exactly how long they would take to complete; if a reaction was believed to take a long time, it would be started in the afternoon so that it could be left to complete overnight as not to waste time during the day waiting for it to finish.

VERIFICATION OF PREVIOUS WORK:

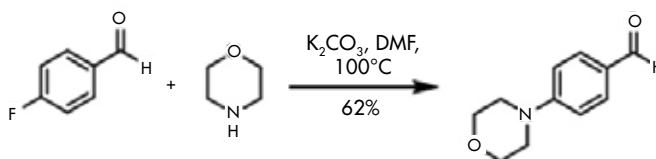
The project that I was doing was a continuation of work previously completed by a group of final-year undergraduate students from the University of Reading earlier this year. During the first week of the project I repeated their work up to the cyclisation reaction, which had been unsuccessful, before going on to make further progress.

It was proposed that this compound would be made according to the retrosynthetic approach below. The benzyl side-chain would be added via an S_NAr reaction, by displacement of chloride. The triazolopyrazine core would be formed by cyclisation of the hydrazone, which would be made from condensation of a hydrazine-pyrazine derivative. Finally, the requisite aldehyde would be made from an S_NAr reaction between 4-fluorobenzaldehyde and morpholine.



For all of the reactions, the specific experimental details and NMR analysis can be found at the end of the project.

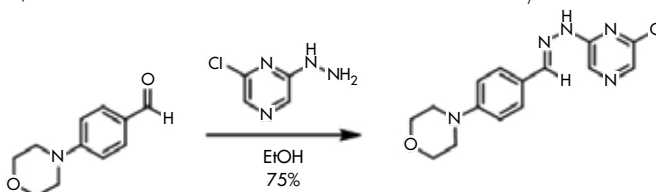
- 1) Nucleophilic aromatic substitution (S_NAr) reaction to synthesise amino benzaldehyde:



This first reaction I was to undertake was the S_NAr between 4-fluorobenzaldehyde and morpholine to form the aldehyde required for condensation. In the reaction, the nitrogen from the morpholine acts as the nucleophile and donates an electron pair to the carbon in the C-F bond, which has a large partial positive charge due to the presence of the highly electronegative fluorine and the aldehyde para to the fluorine. The negative charge generated is able to resonate up into the oxygen in the aldehyde, stabilising the intermediate. This negative charge then pushes back down and expels the fluorine, restoring aromaticity and generating the product.

Potassium carbonate was used in order to mop-up the hydrogen fluoride formed during the reaction. Dimethylformamide was used as the solvent for the reaction, as it is capable of stabilising the charged intermediate. This reaction was successful in producing the amino benzaldehyde with a yield of 62%.

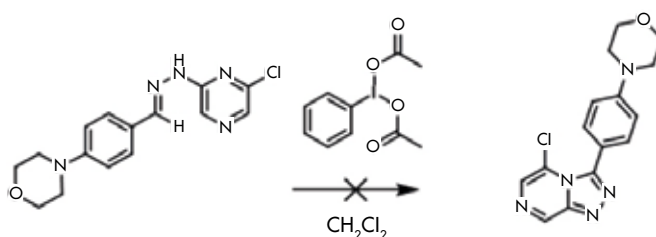
- 2) Condensation reaction to synthesise the requisite hydrazone



The next stage was a condensation reaction between 4-morpholinobenzaldehyde and the hydrazinopyrazine core, which had previously been synthesised, to make a hydrazone. In the reaction, the nitrogen from the hydrazine acts as a nucleophile and donates a pair of electrons to the partially positive carbon in the carbonyl group, forming the hydrazone with water as a by-product. The reaction was completed using ethanol as a solvent and was successful in synthesising the hydrazone with a good yield of 75%.

The next stage was a condensation reaction between 4-morpholinobenzaldehyde and the hydrazinopyrazine core, which had previously been synthesised, to make a hydrazone. In the reaction, the nitrogen from the hydrazine acts as a nucleophile and donates a pair of electrons to the partially positive carbon in the carbonyl group, forming the hydrazone with water as a by-product. The reaction was completed using ethanol as a solvent and was successful in synthesising the hydrazone with a good yield of 75%.

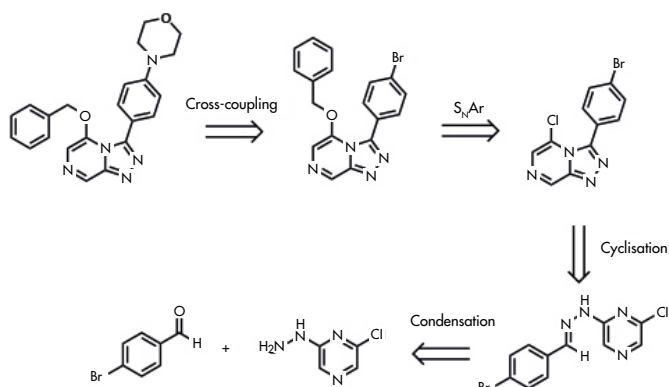
- 3) Cyclisation of hydrazone to synthesise triazolopyrazine:



Having synthesised the hydrazone, the next step was to cyclise it to a triazolopyrazine core. This reaction undertaken using PIDA, (diacetoxyiodo)benzene, as an oxidising agent, in dichloromethane, the solvent. Unfortunately, this cyclisation was unsuccessful and no desired product was isolated. It was postulated that this was due to the presence of the aniline group (benzene ring with a nitrogen directly attached), which meant that the PIDA reacted with the aromatic ring creating polymeric by-products, rather than with the hydrazone as intended. We therefore decided to alter our approach, and attempted the cyclisation step again without the aniline-type functionality present.

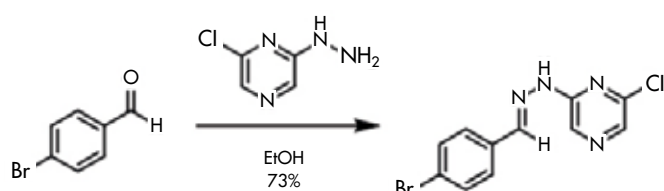
ALTERNATIVE APPROACH AND FURTHER PROGRESS:

Having repeated the work the undergraduate students had previously completed and verifying that it was the cyclisation that was the issue, I was able to complete a series of reactions and make further progress beyond the cyclisation stage towards the target molecule. It was therefore decided to attempt the same processes but in a different order, and without the aniline system in the cyclisation, according to the retrosynthesis below:



Again, experimental details and NMR analysis for all the reactions can be found at the end of the project.

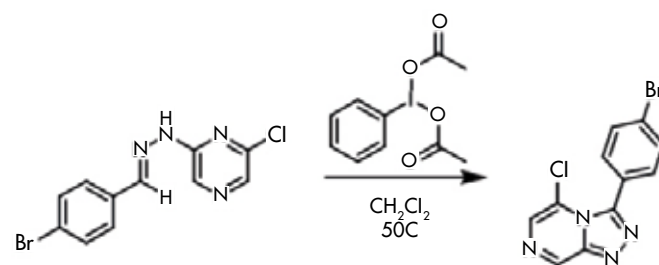
- 4) Condensation reaction to synthesise the requisite hydrazone intermediate:



This reaction is the same as the previous condensation reaction; however, 4-bromobenzaldehyde is used in place of 4-morpholinobenzaldehyde. For this reaction, 4-bromobenzaldehyde was used instead so that a Buchwald-Hartwig cross-coupling reaction could be attempted for the final stage of the reaction pathway.

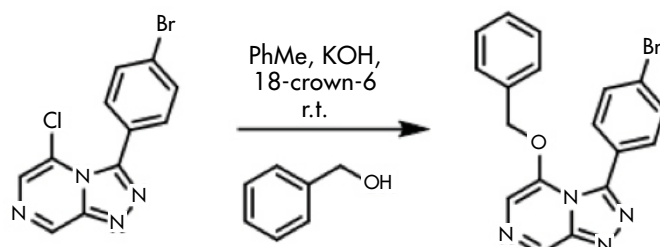
The condensation reaction is between 4-bromobenzaldehyde and the hydrazinopyrazine core to make a hydrazone. Like before, the nitrogen from the hydrazine is acting as a nucleophile and donates a pair of electrons to the carbonyl group generating the hydrazone. Water is formed as a by-product. The reaction was completed in ethanol and was successful in synthesising the hydrazone with a yield of 73%.

- 5) Cyclisation of hydrazone to synthesise triazolopyrazine:



The cyclisation was attempted again using the hydrazone. The reaction was attempted using PIDA ((diacetoxyiodo)benzene) as an oxidising agent, in dichloromethane. This reaction was completed twice. The first time, the reaction was completed on a very small scale (10 mg) inside an NMR tube in deuterated chloroform. Reaction progress was monitored by ^1H NMR spectroscopy over 16 hours. This reaction was successful so the reaction was then repeated using larger quantities. The reaction was also successful, and the product was isolated in 86% yield, which added weight to the hypothesis that the aniline group was the problem.

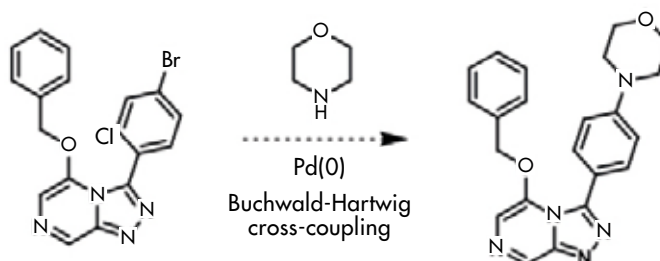
- 6) $\text{S}_{\text{N}}\text{Ar}$ reaction for addition of benzylalcohol to triazolopyrazine:



The next stage of the reaction pathway was the addition of benzyl alcohol to the triazolopyrazine through an $\text{S}_{\text{N}}\text{Ar}$ reaction. The purpose of the 18-crown-6 was to contain the potassium ions during the reaction, therefore the hydroxide anion is more basic and is free to deprotonate the alcohol. The reaction was completed in toluene as the solvent.

This reaction was successful as the crude ^1H NMR showed that the starting material had been consumed and there were new resonances that could be attributed to the target material. However, it was not possible to isolate pure material. Dr Cranwell repeated this experiment at a later date and isolated the required material in quantitative yield.

- 7) Buchwald-Hartwig cross-coupling of morpholine to triazolopyrazine:

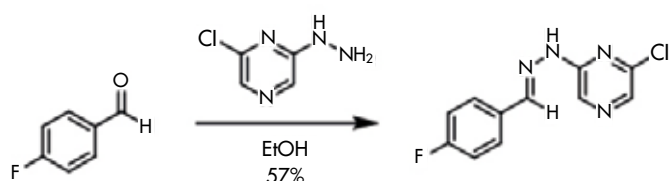


The final stage of the reaction pathway was the installation of morpholine to the triazolopyrazine by a Buchwald-Hartwig cross-coupling. Unfortunately, I did not have the time to be able to do this reaction, and also the previous reaction had been completed on a very small scale so it would have been difficult to do with what starting material I had. If I had had time to do this reaction and it had been successful, then the compound would have been sent to test its activeness in combating malaria.

WORK COULD HAVE DONE:

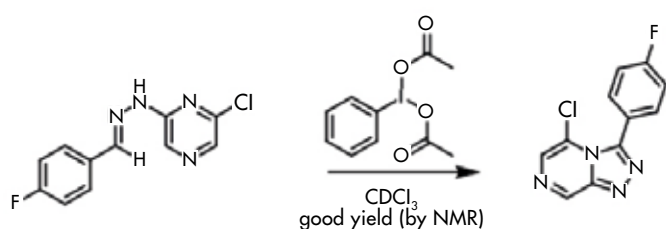
The following set of reactions details work that I completed alongside the work above but was not taken any further at this time. The same reaction pathway is followed however 4-fluorobenzaldehyde is used as the starting compound instead of 4-bromobenzaldehyde. During the project, I was able to complete the first two of these reactions up to the cyclisation stage; experimental details and NMR analysis can be found at the end of the project:

- 8) Condensation reaction to synthesise the requisite hydrazone intermediate:

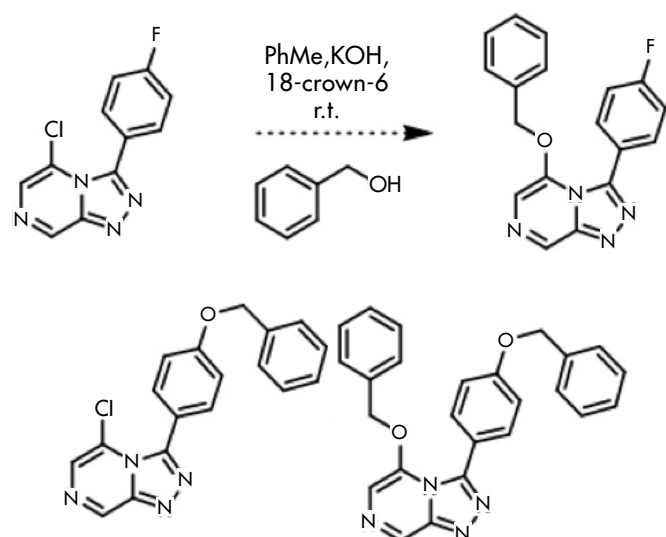


The condensation reaction is between the 4-fluorobenzaldehyde and the hydrazinopyrazine. The hydrazine nitrogen acts as a nucleophile and a pair of electrons is donated to the carbonyl group; water is formed as a by-product. The reaction was undertaken in ethanol and was successful in synthesising the hydrazone. The yield for the reaction was 57%, which is lower than the other two condensation reactions carried out before. No other products were observed.

- 9) Cyclisation of hydrazone to synthesise triazolopyrazine:

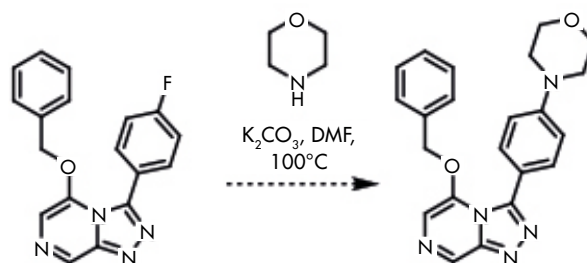


Having synthesised the hydrazine, the next stage was to cyclise it. This reaction is the same as with the previous cyclisation reactions, using PIDA ((diacetoxyiodo)benzene) as an oxidising agent and the reaction being carried out in a solvent of deuterated chloroform. As before, this reaction was completed on a small scale (10 mg) in an NMR



tube so that the progress could be monitored by NMR spectroscopy. It was not repeated on a larger scale. The reaction was successful in synthesising the triazolopyrazine, giving another example to show that the presence of the aniline group caused the first cyclisation to fail. If I had more time to continue with these reactions, the next step would have been to repeat the cyclisation reaction at a larger scale in order to synthesise more product to be used in the next reaction.

The following stage would have been the $\text{S}_{\text{N}}\text{Ar}$ reaction to add on benzyl alcohol. Again, in this reaction 18-crown-6 would be used to contain the potassium ions from the potassium hydroxide, freeing the hydroxide ions for deprotonation and the solvent would be toluene. As shown in the reaction profile, this reaction differs from the equivalent reaction before as there are multiple products that can be synthesised. This is because as fluorine has a higher electronegativity than bromine it is also susceptible to nucleophilic attack, giving two locations on the triazolopyrazine for the benzyl alcohol to be added onto giving three products that can be formed.



Having added the benzyl alcohol to the triazolopyrazine and separating out the desired substitution product, the final stage to synthesise the target molecule would be to add morpholine via an $\text{S}_{\text{N}}\text{Ar}$ reaction. This reaction is an $\text{S}_{\text{N}}\text{Ar}$ reaction using the same reagents and conditions as when morpholine was added to the 4-fluorobenzaldehyde before. The nitrogen from the morpholine acts as the nucleophile, donating an electron pair to the partially negative fluorine. The potassium carbonate is present to mop up the hydrogen fluoride created and the solvent is dimethylformamide.

DISCUSSION OF RESULTS AND CONCLUSION:

Although I was not able to synthesise the target compound, I still believe that my project has been successful and am pleased with the progress made towards it all the way up to the penultimate stage. By documenting these reactions, it will mean that anyone who attempts to synthesise the same target molecule should have an effective method to follow.

The project has shown that the $\text{S}_{\text{N}}\text{Ar}$ reactions were a successful route to take for the pathway, with only one exception to them working successfully. Even then, the cause for the failure (presence of aniline group) was identified and a change made to the reaction order meant that the problem could be overcome and further progress made.

The percentage yields also show evidence that the $\text{S}_{\text{N}}\text{Ar}$ reactions were very effective, ranging from 57% to 86%. The main reason for the drops in yields will have likely been due to incomplete reaction. A counter to



this would be to increase the equivalents of the amine at the start so that completion could be totally ensured. Inevitably there will also have been some product lost during transfer and if samples were taken for NMR analysis before the product was fully purified.

Therefore, if I were to repeat the project I would use S_NAr reactions again as they have proven successful. However, some of the substances used in the reactions can be changed to improve their speed and efficiency. For example, in the benzyl alcohol reaction, a different base could have been used as potassium hydroxide and 18-crown-6 meant the reaction was very slow. In addition, 18-crown-6 is expensive so would be costly if this reaction was scaled up. Using a different base, such as sodium hydride, may increase the rate.

Since July 2017, Dr Cranwell has continued to make further progress. She has carried out the final stage (adding the morpholine to create the target molecule) successfully, synthesising the target molecule with a good yield. By sharing the project information on the OSM website, she has received interest and feedback on how the reaction pathway could be improved. As of April 2018, a scientist in Sydney has since used the project data to re-synthesise the target molecule along with three other variations. This was especially exciting for me as it showed the credibility of work I had contributed to and it means that these molecules will also be biologically tested against the malaria parasite in the near future.

NEW TECHNIQUES AND EQUIPMENT:

During the project, I was introduced to multiple new techniques and pieces of equipment that were frequently used in all of the reactions I completed. For each one listed below, I have both explained how they work and what their purpose was in relation to the reactions:

□ Thin layer chromatography:

Thin layer chromatography (TLC) is used to separate out a mixture into its constituent parts and was predominantly used in my reactions to see how far a reaction had progressed by seeing if it contained any more starting material. TLCs were also used during flash chromatography (see below) to determine whether each fraction contained any material.

TLCs were carried out in a sealed chamber that contained a piece of filter paper in contact with the solvent. For all of the TLCs I did, the solvent was a mixture of ethyl acetate and petrol ether (together EtOAc/Pet. ether) – typically 20% or 50% ethyl acetate. The combination of sealing the chamber and having the filter paper means that the chamber is saturated with the solvent, which was volatile, therefore the solvent will not evaporate as it moves up the plate (Clark, 2007). The plate that was used in all my TLCs was made from an aluminium sheet, coated in silica. On the base line of the plate, drawn in pencil, I would have three crosses marked starting material, mix and reaction.

Using a pipette, I would dab small amounts of the starting material onto both the starting material and mix crosses and small amounts of the reaction mixture onto the mix and reaction crosses. Then I would place the silica plate in the chamber with the solvent on the base-line end. Having let the solvent travel to within a centimetre of the top of the plate I would remove it from the chamber and draw another pencil line where the solvent had reached. I would then look

at the plate under UV light (either at wavelengths 254 nm or 366 nm) and trace with a pencil any visible spots. I was able to compare the three crosses to see if the reaction still contained any starting material or whether it was completed.

On top of doing TLCs, I also used three different stains to help interpret the results. The TLC plates were stained after being removed from the chamber and visualised under UV. To stain them, they were immersed in the stain up to the solvent line and then heated gently with a heat gun. The first stain I used was a vanillin stain, which colourises the different spots that I would trace under the UV light. Different materials are often stained different colours so materials with the same R_f value can be differentiated. The second stain used was iodine which is used to identify organic compounds, especially unsaturated and aromatic ones (Chemistry McMaster, 1991). Iodine is a useful stain as it is reversible. Finally, potassium permanganate stain was used to identify compounds that are able to be oxidised. These turn bright yellow, while the rest of the plate remains purple.

□ Flash chromatography:

Flash column chromatography or, more colloquially, columning, was a technique used frequently during my reactions to purify the crude product. The column was set up firstly by adding a thin layer of sand then preparing a slurry consisting of silica gel and the eluent (Wikipedia, 2015). With the columns that I completed, the eluent was a mixture of ethyl acetate and petrol. The silica gel slurry is added on top of the sand, and the solvent is run through the column under air pressure to compact the silica allowing sample separation. The silica is the stationary phase, and the organic solvent the mobile phase. Next, the organic crude product is carefully pipetted down the sides of the column as a solution in the eluent, to create an even layer on top of the silica, and a layer of sand is put on top of that to prevent the layer being disturbed by the addition of the solvent. The eluent used was a mixture of ethyl acetate and petrol ether, with the proportion of ethyl acetate increasing with each new batch.

Increasing the proportion of ethyl acetate in the solvent leads to increased polarity, resulting in the eluent interacting with the silica surface more than it does with the organic product. Therefore, the product will progress down the column quicker with less interactions taking place, eluting faster.

Once the solvent was added the tap was opened and the column was pressurised using hand bellows to increase the rate at which the solvent passed through the column. Fractions were collected in vials/test tubes of appropriate size to the column. TLCs were taken of all the fractions to see whether they contained anything – including the purified product.

A column is in effect an upside-down TLC, with spots from the top of the TLC eluting from the column first as they are least polar.

□ Rotary evaporation:

Rotary evaporation is a form of distillation used in my experiments to evaporate the solvent from the product. The process is similar to distillation I have done at school with some differences; firstly, the solution containing the sample is gently heated in a round bottomed flask that is being rotated, which creates a large surface area for heating as the solvent is spread in a thin layer across the flask (Wikipedia, 2016). The



solvent evaporates away from the product and travels to the condenser, containing dry ice in a cold-finger, which cools and condenses the solvent, which falls into another round bottomed flask to be discarded later. Another key difference is that the apparatus is under vacuum, which lowers the boiling point of the solvent meaning that it is able to evaporate off the product at much lower temperatures (25–35°C) in a water bath.



A rotary evaporator very similar to the one used during the project. On the right is the flask that would contain the product and solvent in a water bath. The dry ice condenser can be seen on the left hand side along with the taps where the vacuum pump would be attached to and the removable flask where the solvent was collected.

□ NMR spectroscopic Analysis:

While at Reading, NMR spectroscopy was used after all reactions to determine the structure of the molecules that had been made. It was really exciting to be able to use NMR spectrometers and interpret spectra from real life samples, having just learnt about it at school. These spectrometers were crucial to see whether the reaction had been successful, as well as seeing if anything else had formed or if there were any impurities present. For all new compounds that I prepared (i.e. they had never been prepared by anyone else in the world before), full data analysis was collected by the NMR spectrometers.

The most common use of the machines was for ^1H NMR; however, we also collected many ^{13}C and occasionally ^{19}F NMR spectra, each of which provide the number of environments for each element. The proton spectra show the relative number of protons per environment and number of peaks (resonances) showing the number of surrounding protons. Each of the different spectra produced would give information that allowed me to piece together which peaks on the ^1H and ^{13}C spectra corresponded to an environment on the molecule.

In addition to the regular 1-dimensional data, we also collected numerous 2-dimensional NMR spectra, including DEPT, COSY, HMQC and HMBC data:

- **DEPT:** The DEPT spectrum shows all the carbon environments with protons attached to them (CH , CH_2 , CH_3) with CH and CH_3 on one side of the base line and CH_2 on the other side.

- **COSY:** The COSY scan is a 2-dimensional experiment that shows which proton environments are in close contact with each other by bonding. Protons 3–4 bonds away from each other will interact with each other. The COSY spectra were especially useful to quickly identify proton environments in close proximity such as in rings, like benzene.
- **HSQC:** HSQC spectra are also 2-dimensional experiments that are used to show which proton environment corresponds to each carbon environment, with only protons directly bonded to the carbon showing up on the spectra.
- **HMBC:** The HMBC is similar to the HSQC spectrum and is also 2-dimensional; however, it shows which proton environments are in close contact with carbon environments (3–4 bonds away).

EXPERIMENTALS:

1) $\text{S}_{\text{N}}\text{Ar}$ reaction to synthesise amino benzaldehyde:

4-Fluorobenzaldehyde (2.32 mL, 16.1 mmol) was taken into dimethylformamide (25 mL) followed by the potassium carbonate (5.6 g, 40.3 mmol) in one portion to give a cloudy suspension. Finally, the morpholine (1.83 mL, 21.0 mmol) was added and the solution remained cloudy. The reaction was left stirring at 100°C with an air condenser overnight for eighteen hours, after which time the solution remained cloudy and had turned a slightly darker colour to a white/yellow colour.

TLC analysis (20% EtOAc/Pet. ether) was undertaken and confirmed that the reaction was complete. The reaction mixture was cooled to room temperature and then quenched in water and the product extracted into ethyl acetate. The organic layer was then dried with magnesium sulfate, filtered, and the solvent removed *in vacuo*, using a rotary evaporator.

The product was purified by flash chromatography on silica gel (20%–50% EtOAc/Pet. ether) to give the product as a white solid (1.89 g, 9.88 mmol, 62%).

A full NMR analysis of the product was then taken (^1H , ^{13}C , DEPT, COSY, HSQC, HMBC) in deuterated chloroform (CDCl_3), along with an IR spectrum.

2) Condensation reaction to synthesise the requisite hydrazone intermediate:

4-Morpholinobenzaldehyde (1 g, 5.23 mmol) was taken into ethanol (16 mL). While stirring, a heat gun was used to fully dissolve the 4-morpholinobenzaldehyde to give a pale-yellow solution. The hydrazinopyrazine core (0.797 g, 5.49 mmol) was added in portions to give an orange, cloudy solution, and eventually an orange/red precipitate once it was all added. More ethanol was added to dissolve the precipitate, totalling approximately 24 mL. The reaction was left for 90 minutes at room temperature, over which time a light brown precipitate was formed.

TLC analysis (20% EtOAc/Pet. ether) was undertaken to confirm the reaction was complete. The product was separated from the ethanol using suction filtration. The crude product was left in a vacuum oven overnight for fifteen hours to remove residual ethanol, giving the product as a light brown solid (1.25 g, 3.94 mmol, 75%).



A ^1H NMR analysis was taken of the product in deuterated dimethyl sulfoxide (DMSO). Both a vortex stirrer and sonicator were used to dissolve the product in the solvent.

3) Cyclisation of hydrazone to synthesise triazolopyrazine:

The hydrazone (0.52 g, 1.64 mmol) was taken into dichloromethane (8 mL). The PIDA (0.58 g, 1.80 mmol) was added – no observable changes were made on the addition of the PIDA. The solution remained a brown precipitate and was left at 50°C with an air condenser for five hours, where the precipitate had turned a slightly darker brown colour.

TLC analysis (50% EtOAc/Pet. ether and 50% EtOAc/Pet. ether with triethylamine) was undertaken to confirm the reaction was complete. Both were stained with iodine and vanillin. The reaction mixture was quenched with sodium hydrogen carbonate and the product extracted into ethyl acetate. The organic layer was dried with magnesium sulfate, filtered and the solvent was then separated *in vacuo*, using a rotary evaporator.

The product was purified by flash chromatography on silica gel (30%–100% EtOAc/Pet. ether). ^1H NMR analysis taken in CDCl_3 showed the reaction was unsuccessful.

4) Condensation reaction to synthesise the requisite hydrazone intermediate:

4-Bromobenzaldehyde (0.51 g, 2.70 mmol) was taken into ethanol (4 mL) followed by the hydrazinopyrazine core (0.41 g, 2.84 mmol) to give a light brown precipitate on addition. More ethanol was added dropwise to allow the reaction mixture to stir, totalling approximately 12 mL. The reaction mixture was left at room temperature for 75 minutes where the precipitate had turned a slightly lighter brown colour.

TLC analysis (20% EtOAc/Pet. ether) was undertaken with a vanillin stain to confirm the reaction was complete. The product was separated from the ethanol using suction filtration and left in a vacuum oven to remove any residual ethanol leftover to give the product as a light brown solid (0.62 g, 1.99 mmol, 73%).

^1H NMR analysis of the product was taken in two different solvents, CDCl_3 and DMSO.

5) Cyclisation of hydrazone to synthesise triazolopyrazine (smaller scale):

The hydrazone (12.1 mL, 0.032 mmol) was taken into deuterated chloroform (800 μL) followed by the PIDA (12.8 mg, 0.034 mmol). On adding the PIDA there were no observable changes, with the solution having a light brown/yellow precipitate colour. ^1H NMR data were collected hourly overnight to show the reaction's progression, totalling 16 hours. After this time the reaction mixture had turned a lighter yellow colour and was no longer cloudy.

^1H NMR analysis showed the reaction had been successful.

6) Cyclisation of hydrazone to synthesise triazolopyrazine (larger scale):

The hydrazone (199 mg, 0.64 mmol) was taken into dichloromethane (6 mL) and PIDA (220 mg, 0.67 mmol) was then added, along with dichloromethane (approximately 1 mL) to allow the reaction mixture to stir properly. The reaction mixture was a light brown/yellow precipitate and there were no observable changes on adding the PIDA. The reaction was left to stir at room temperature. After three hours, the precipitate had turned a slightly lighter colour.

TLC analysis (50% EtOAc/Pet. ether) was taken to confirm the reaction was complete. The reaction mixture was quenched with sodium hydrogen carbonate and the product extracted into dichloromethane. The organic layer was dried using magnesium sulfate, filtered and the solvent was removed *in vacuo*, with a rotary evaporator.

The product was then purified with flash chromatography on silica gel (30%–60% EtOAc/Pet. ether) to give the product as a brown solid (170 mg, 0.55 mmol, 86%).

^1H NMR analysis was taken in CDCl_3 .

7) SNAr reaction for addition of benzylalcohol to triazolopyrazine:

The triazolopyrazine (48 mg, 0.16 mmol) was taken into toluene (1 mL). Benzyl alcohol (0.016 mL, 0.16 mmol) and the 18-crown-6 (3 mg, 0.015 mmol) were added sequentially. Finally, the potassium hydroxide (9 mg, 0.016 mmol) was added. The solution turned a darker brown/yellow colour and was left stirring at 50°C with an air condenser. The reaction was left to continue for 2 days over the weekend, where the toluene evaporated and a white/yellow crust had formed on the side of the flask. Three pipettes of toluene were added to re-dissolve the solid.

TLC analysis (50% EtOAc/Pet. Ether) was taken with a potassium permanganate stain and showed the reaction was complete. The reaction mixture was quenched with 2M hydrochloric acid and the product extracted into ethyl acetate. The organic layer was then dried with magnesium sulfate, filtered and the solvent removed *in vacuo*, using a rotary evaporator. ^1H NMR analysis was taken of the crude product in CDCl_3 , which suggested product was formed.

The product was then purified with flash chromatography on silica gel (50%–100% EtOAc/Pet. ether). Two sets of fractions were identified, isolated and ^1H NMR analysis was taken of each in CDCl_3 ; however, neither contained the requisite material.

8) Condensation reaction to synthesise the requisite hydrazone intermediate:

4-Fluorobenzaldehyde (0.43 mL, 4.03 mmol) was taken into ethanol (4 mL). Next the hydrazinopyrazine core (0.61 g, 4.23 mmol) was added to give a light brown precipitate. More ethanol was added drop-wise to allow the reaction mixture to stir, totalling approximately 12 mL. The reaction mixture was left at room temperature for 75 minutes, where the precipitate had turned a slightly lighter brown colour.

TLC analysis (20% EtOAc/Pet. ether) was taken, with a vanillin stain was used confirm the reaction was complete. The product was separated from the ethanol using suction filtration and left in a vacuum oven to remove any residual ethanol to give the product as a brown solid (0.576 g, 2.30 mmol, 57%).

^1H NMR analysis was taken in two different solvents, CDCl_3 and DMSO.

9) Cyclisation of hydrazone to synthesise triazolopyrazine:

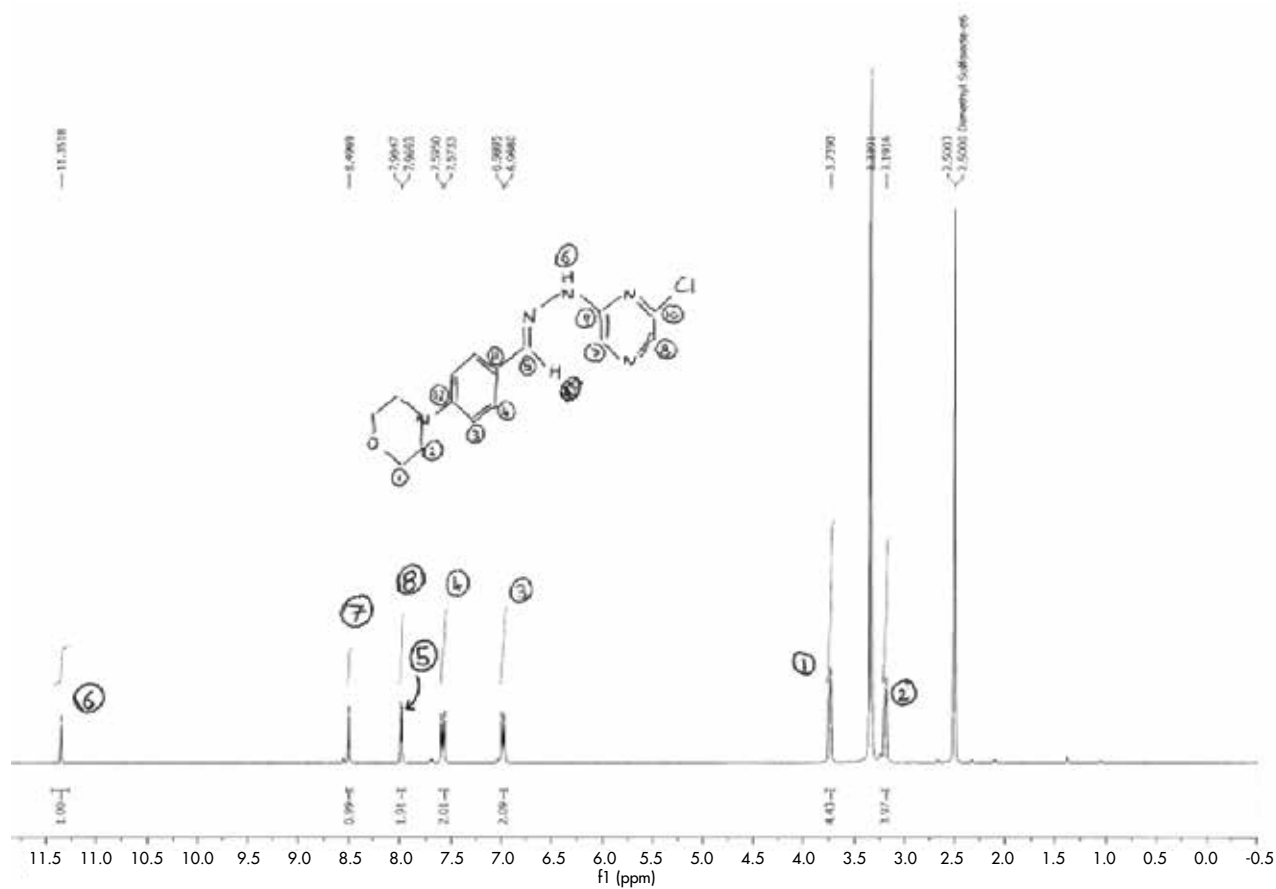
The hydrazone (10 mg, 0.039 mmol) was taken into deuterated chloroform (800 μL) followed by the PIDA (13.3 mg, 0.044 mmol). On adding the PIDA there were no observable changes with the solution having orange/pink precipitate colour. ^1H NMR spectra were collected overnight to follow the reaction's progress. After sixteen hours the reaction mixture had turned a lighter yellow colour and was no longer cloudy. ^1H NMR data suggested the reaction was successful.



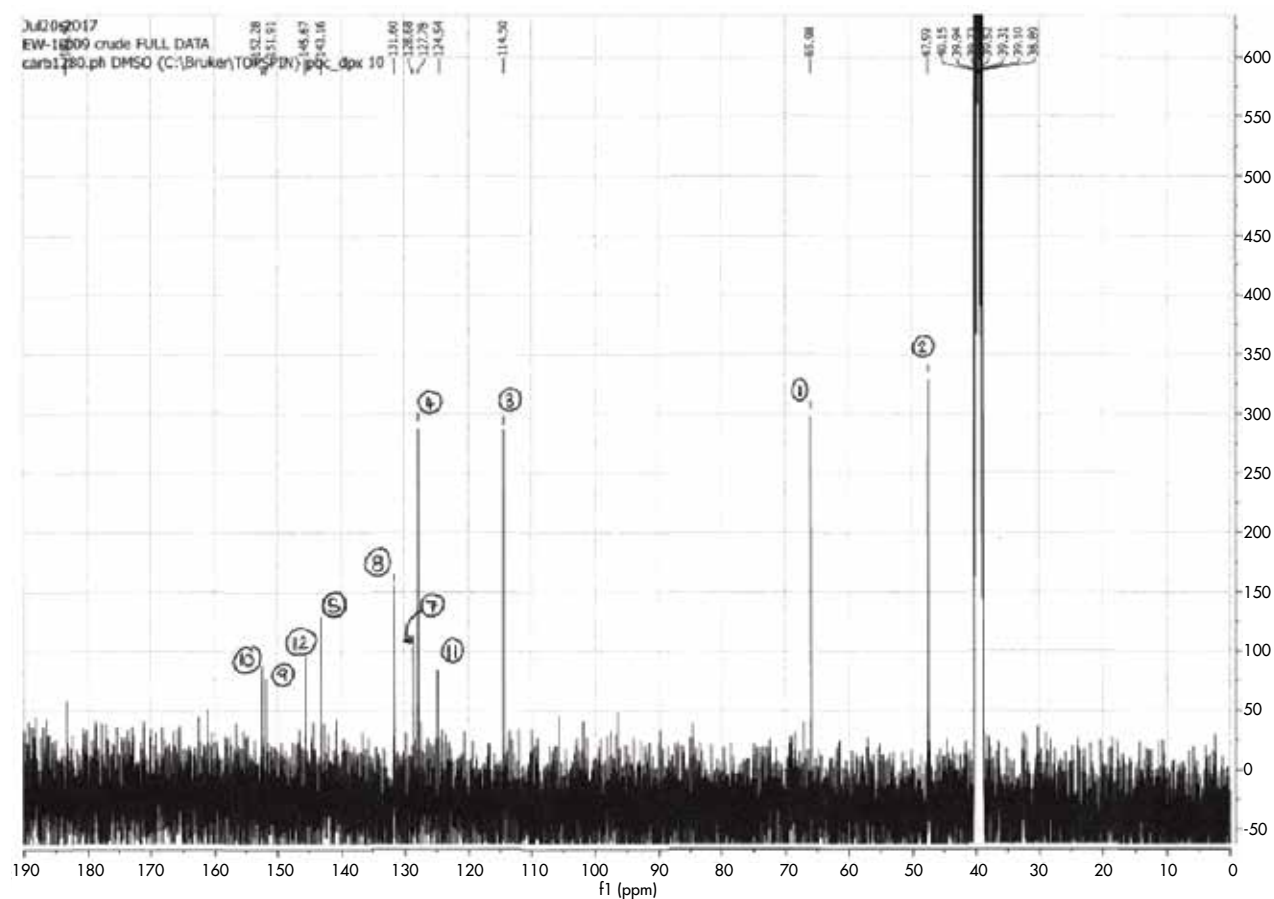
APPENDIX:

An example of the NMR analysis I carried out is shown below, including ^1H and ^{13}C spectra, as well as DEPT, COSY, HSQC and HMBC spectra:

^1H :

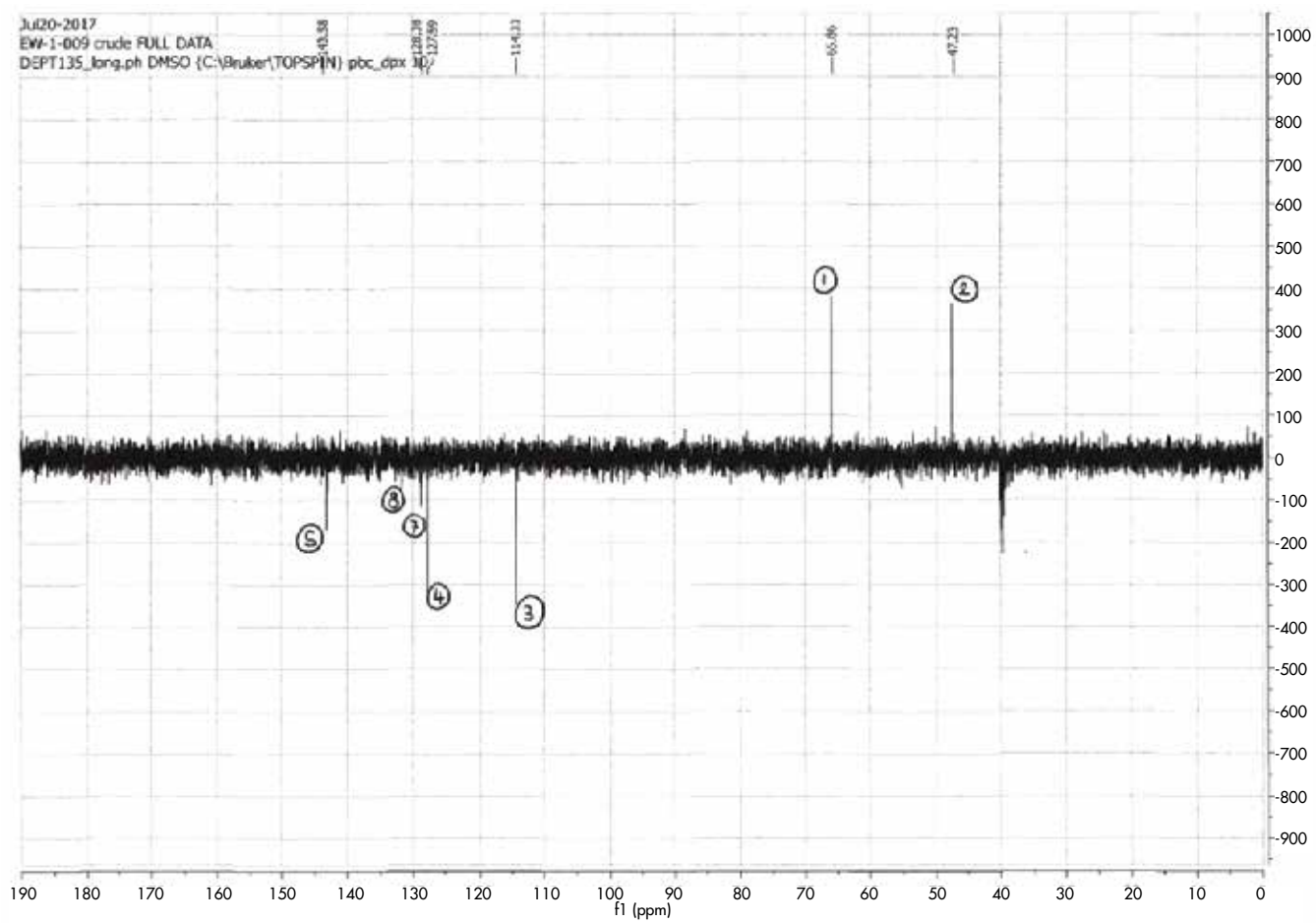


^{13}C :

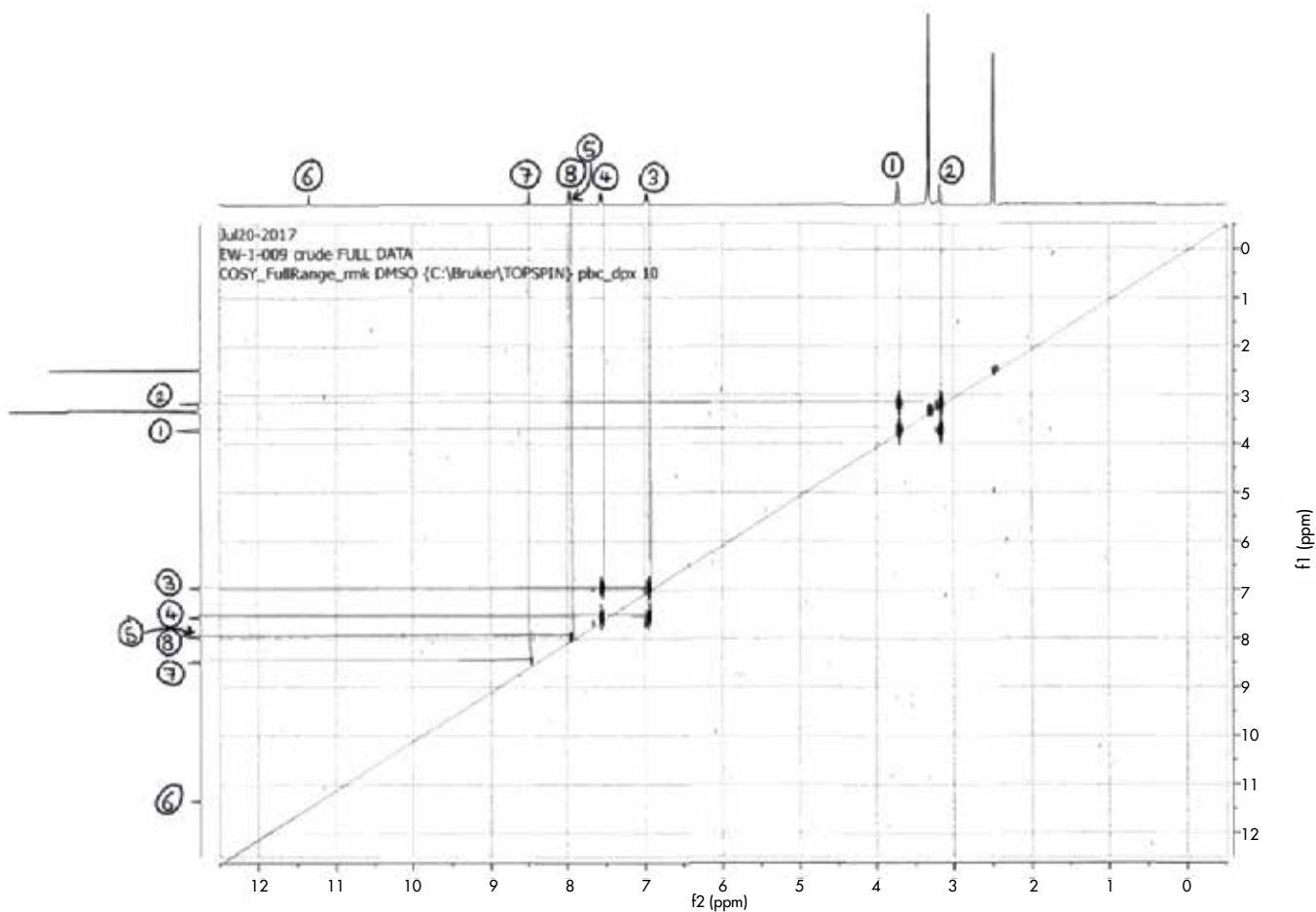




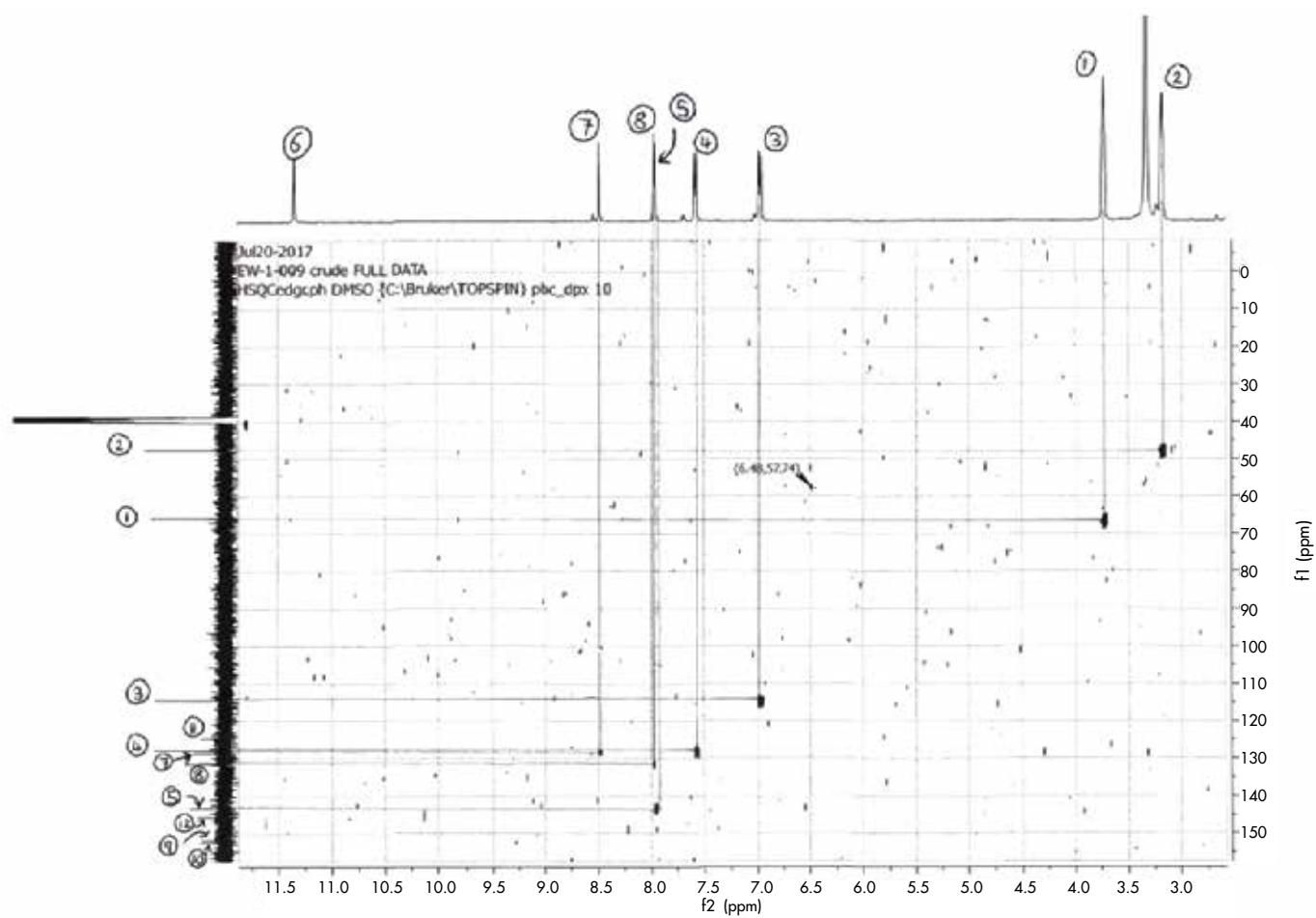
DEPT:



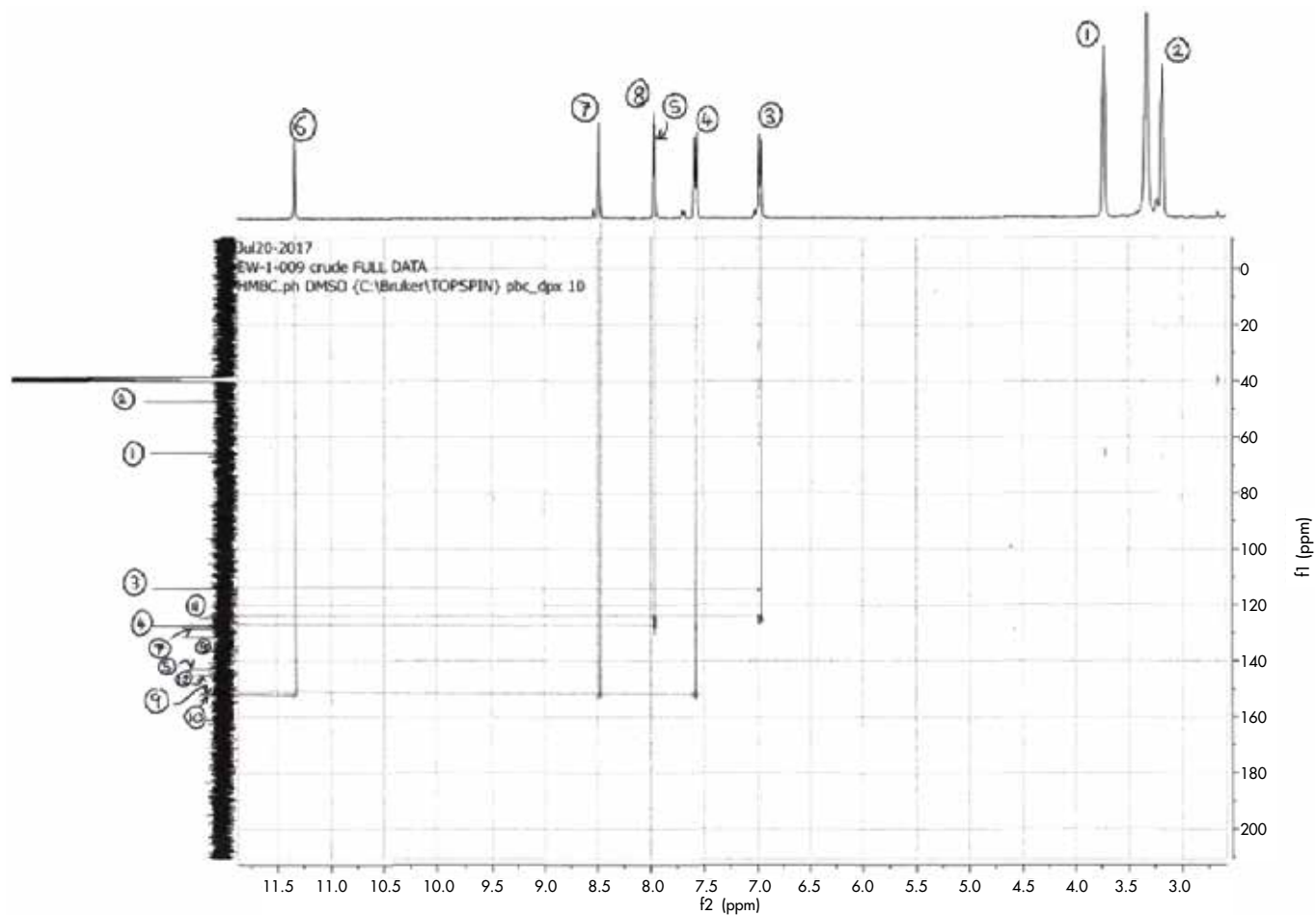
COSY:



HSQC:



HMBC:





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I am extremely grateful to Dr Philippa Cranwell for giving me the opportunity to do research for a Crest Gold Award this summer. As well as guiding me through the project and the reaction pathway I would be doing, Dr Cranwell was also there to answer any questions I had or explain any of the new techniques/equipment in a way I was able to follow and understand.

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To what extent is Islam an outdated religion?

Yusuf Hafiz

Now more than ever before with the advent of modern media, Islam is being criticised for being an outdated, backwards religion that is out of place in the modern liberal society we have today. Homophobia, misogyny and violence, all apparently grounded in the divine infallible word of God, the Qur'an, manifest themselves in the version of Sharia law practised throughout the Middle East, which to many suggests that Islam is severely outdated and should undergo some sort of reform. I claim that such criticisms are misguided: there does seem to be an apparent problem with Islam today, but I argue that it is not a problem with Islam as much as it is a problem with a minority of today's Muslims choosing to interpret Islam in a perverse way. As a practical book, many of the Qur'an's verses are responses to problems at the time, verses on marriage and war, and they are perfectly justifiable within their contexts; a minority of Muslims decide to take these verses out of their context and to add their own interpretations, many of which have no valid justification at all. I argue therefore that the problems associated today are not caused by Islam itself, but by those Muslims interpreting it.

SHARIA

This year, the UK-based Syrian Observatory for Human Rights estimates at least 25 people have been killed by ISIS for being gay and more than 4000 executed for crimes such as apostasy and sodomy, some of which were women and children, all grounded in their belief in Sharia law. It is unquestionably outdated; capital punishment is still in place, not even just for major crimes such as murder or serial rape, but also for acts such as homosexuality and polytheism, and in countries like Saudi Arabia and Qatar women are severely discriminated against. In today's world, discrimination of homosexuals or any minority is heavily frowned upon, and to have them executed is unconceivable. The precepts and principles behind such laws are found in the Qur'an, what is believed to be the exact word of God; the implications of this for a Muslim are that anything stated in the Qur'an is impossible to refute. As these precepts or principles are found in the Qur'an, and the Qur'an is at the centre of Islam and is the direct word of the God of Islam, this strongly suggests that there is no getting around the fact that the very essence of Islam is outdated and has no place in modern society.

The issue of Sharia law demonstrates the problem of interpretations today and clearly suggests that Muslims are the cause of the controversy with Sharia law today, not Islam and the Qur'an. Sharia law is not the actual law applied in countries such as Saudi Arabia, this is Fiqh. In Arabic, Sharia refers to the immutable divine law of Allah, contrasted with Fiqh, which refers to its human scholarly interpretation. Al-Sharia, literally 'the path to the water hole' is a set of principles (principles like equality, justice, and the importance of linking rights to responsibilities and risks to rewards) promoting a

set of simple practices (like living humbly, serving God and minding your own business) and these are the precepts that Muslims believe are divinely ordained and therefore perfect and unquestionably good. Traditionally there are four sources of Sharia: Qur'an, Sunnah, qiyas (analogical reasoning), and ijma (juridical consensus). To give an example of how this works is the ruling on smoking. It is widely accepted in Islam that smoking is not permitted, yet there is no direct reference to smoking in the Qur'an or Sunnah, rather scholars have engaged in qiyas, they have taken the core principle that Muslims are forbidden in consuming anything harmful, and applied it to smoking. On the contrary however, some more radical scholars have produced fatwahs (legal opinions) condemning the consumption of fast food and confectionery as they are harmful to us, and as this demonstrates, there are huge deviations in interpretation when it comes to the Sharia. The illegitimate interpretations of extremists around the world don't show that Islam is outdated or discriminatory in any way, rather they reflect the views of the interpreter, which suggests that Muslims are to blame for extreme interpretations of the Sharia; the Sharia itself isn't extreme or even outdated.

MISOGYNY

Islam is also a misogynistic religion; in Islam traditionally it is seen that women are less equal than men, and the justification for this lies in the Qur'an, the undisputable divine word of God. In the Qur'an, women get less inheritance than men, their testimony is worth less than that of a man, men are allowed up to four wives, but women only one husband, all of which suggest that men are intrinsically of greater significance and importance than women. Moreover, inference can be made over this point by taking the example of Muslim majority countries such as Saudi Arabia or Qatar where women are clearly discriminated against, women aren't allowed to make major decisions without the consent of men for example, and women aren't allowed to compete freely in competitive sport. This shows that Islam is a religion that does not value women as equal to men, actively discriminates against women and thus is an outdated religion not suitable in modern times.

As discussed before, Sharia in countries such as Saudi Arabia and Iran cannot be used as evidence for Islam being backwards as their interpretations can be discredited. In this way, you cannot claim that Islam is objectively prejudiced against women based on what you see in Saudi or other Arab countries. A substantial amount of context is needed to discuss this matter. In the 7th century, Mecca was a trading centre, Muhammed was a trader or a merchant, and so was his first wife Khadija. Entrepreneurship was very much the primary profession of anyone living in Mecca at the time. It was not the safest job either: Mecca was a cut-throat place, and because of this it was a Meccan



tradition to send children off to Bedouin families as that kind of lifestyle was considered healthier than that of the hustle and bustle of a trading town like Mecca. Not only was Mecca unsafe, the merchant profession was unsafe; highway bandits were a huge problem, and there are multiple references to the problem of highway bandits in the Hadith and Seer'ah. It is because of all of this that the protection of women became an important part of Islam at the time and I argue that the reason for such verses in the Qur'an is for the protection of women. These verses were meant specifically for the context of 7th century Arabia and only their essence, not specific content, should be applied today.

On inheritance, the verse, Surah An-Nisa verse 11 reads "A son's share is equal to the share of two daughters". Women were to get half as much inheritance as men because and only because it was the men in those days who looked after the family. In the Arabian culture (which had nothing to do with Islam) men worked and provided for the family and settled any expenses that needed settling, thus much of the man's money went towards the rest of the family. The woman's money on the other hand was purely for herself, she has no duty to provide for the family, thus she gets less inheritance; in the end, the woman most probably ended up with more disposable income anyway. In today's society, where many women do provide for themselves, this verse becomes redundant and certainly doesn't show any form of discrimination.

There are multiple reasons as to why men can have four wives, but not the other way around, in Surah An-Nisa verse 4 it states "marry those that please you of [other] women, two or three or four". Justification for this linked to the point above is the cultural reason, to protect women from society. In 7th century Arabian society, not only was it extremely hard for ordinary women to support themselves, but there were multiple husbandless women due to wars and dangerous professions; the number of women was far greater than the number of suitable men, thus men could marry more than one woman to support her, not because women are unequal but because in that society women needed protecting. An example of this was Muhammad's marriage to Hafsa bint Umar, daughter of Umar, whose husband was killed in the battle of Badr. Muhammed was simply protecting the daughter of one of his closest companions. Again, I would argue that the principle of this practice, protection of women, cannot be applied today in the form of marrying more than one woman, therefore this need not be practised today.

In terms of testimony this again can be explained contextually. First we must establish that what is meant by witness or testimony is something by which the thing testified may be proven and known to be true and correct, so it is information about it. Surah Al-Baqarah verse 282 reads "...And get two witnesses out of your own men. And if there are not two men (available), then a man and two women, such as you agree for witnesses, so that if one of them (two women) errs, the other can remind her...", and states that two women are needed as opposed to one so that if one 'errs' the other can remind her. Again, this can be explained by context, as mentioned women in those days didn't go out much, their role was to stay at home to look after the family, so in matters pertaining to work or life outside of the house women are by virtue of staying at home less knowledgeable, so of course their testimony is going to be of less value. This is not discriminatory, it is simply a brute fact and it gives

no grounds for anyone to view Islam and discriminatory, nor does it give grounds for Muslims to discriminate.

HOMOSEXUALITY

The Islamic stance on homosexuality is an issue that sets apart Islam from much of the modern world. In Islamic countries, such as Saudi and Iran, under Sharia law homosexuality is punishable by death and the fundamentalist group ISIS have been shown to throw homosexuals off buildings. Recently, mysterious posters began to appear all over the East End of London announcing it is now a "Gay-Free Zone." They warned: "And Fear Allah: Verily Allah is Severe in Punishment." More homophobic incidents have occurred recently in East London, some going as far as stabbings. East London has seen the highest increase in homophobic attacks anywhere in Britain, and some of the worst in Europe. Many suggest it is because East London has the highest Muslim population in Britain, and we have allowed a fanatically intolerant attitude towards gay people to incubate there. This then shows a clear link between Islam and homophobia. A recent poll carried out by Gallup showed that no British Muslims accept homosexual acts as 'morally acceptable'. It seems therefore that it is part of the Muslim culture to be bigoted towards homosexuals, something that was happening over 30 years ago in the UK, which goes to show that Islam is in fact outdated.

It is true that in Islam homosexual acts are sinful and immoral, but immoral in the sense that adultery and the consumption of alcohol are immoral, but this does not mean it is punishable by death, nor does it mean you cannot be Muslim and gay at the same time; there is no sin that expels one from Islam unconditionally. Homosexuality is referred to in the Qur'an in only two places; the first is in Surah An-Nisa verse 16: "If two men among you are guilty of lewdness, punish them both. If they repent and amend, leave them alone, for Allah is oft-returning, most merciful". The second is in the story of Lot in the Qur'an, in Surah Al-A'raaf: "For ye practise your lusts on men in preference to women, ye are indeed a people transgressing beyond bounds" ... "and we rained down on them a shower of brimstone, then see what was the end of those who indulged in sin and crime". The latter has been the apparent justification for stoning adulterers and homosexuals for many years across the Middle-East. Here homosexuality is described as a sin, and nothing but a sin, in the same way that an adulterer or a thief or someone who drinks and gambles is a sinner. It is the act of homosexuality that is the sinful part rather than the disposition, the disposition is something that you can't help, just like a kleptomaniac can't help but steal, and it is unfair to punish someone for such a thing. The Qur'an and Hadith point to the fact that sinning and being Muslim are not mutually exclusive since as a matter of fact we all sin, a Hadith reported by Sahih Muslim reports that Muhammed once said "I swear by the One in whose hand is my soul! If you did not commit sins, Allah would have surely gotten rid of all of you, and He would have surely brought another people who would commit sins – so that they would then seek Allah's forgiveness (for their sins) and so He would forgive them". I suggest that being homosexual and Muslim shouldn't be self contradictory. Being homosexual and Muslim is essentially the same as being a gambler and Muslim, or having sex outside of marriage and being Muslim,



which many people have no problem with. It is entirely hypocritical therefore to argue that one can drink alcohol and be Muslim but not be gay and Muslim, there must be some coherence. If you don't believe that you can sin and be Muslim then that is a different problem all together, but as long as you hold that you can sin and be Muslim at the same time you cannot possibly hold that you cannot be gay and Muslim at the same time.

The justification for stoning homosexuals comes from the verses stated above, "shower of brimstone" which can suggest execution via stoning. It is ambiguous to interpret the verse to condone stoning of homosexuals to take God destroying a city of sinners because of their crimes and their immoral influence on the rest of the land, and to jump to homosexuals are to be executed or at least punished in some manner is a huge unjustified inductive leap. Whether homosexuality is a crime is up to interpretation; there is certainly no verse stating all sins are crimes in the Qur'an or Hadith. It is as much of a sin or crime as adultery, so if a culture decides it is justified to execute adulterers, then executing homosexuals in that context in their eyes is justified; whether or not this is right is another issue. However, if they don't stone adulterers and just homosexuals, this is wrong as it is prejudice. I would argue that this view is supported by the verse, the verse says the city is destroyed because of all the crimes and sins going on, it doesn't single out homosexuality, so to stone homosexuality based on this verse you would have to stone everyone doing any sin in the verse, alcohol, drugs, highway robbery, which no one would agree with. I therefore conclude that there lies no justification in this verse for the stoning of homosexuals specifically. Moreover, I would argue that Islam provides no justification for stoning at all; there is no mention of stoning in the Qur'an as a punishment, and the only punishment listed for adultery is lashes. The punishments given for certain perceived crimes are entirely subjective upon the civilisation. If a society decides that execution is fit for the above crimes, it has no grounding in any Islamic texts and therefore is not Islam, rather the Muslims setting out the laws.

TERRORISM

Terrorism is perhaps the most prominent issue with Islam and is the biggest criticism it faces. There is no doubt that Islamic terrorism in Europe is on the rise and is a huge problem, and there is no escaping that there seems to be some religious element to it, with many attackers if not citing the Qur'an as their justification, at least having strong links to Islamic state. It seems as though Islam is a warring, backward, violent religion. Islam has brought us 6 terrorist attacks in the UK in the last 12 years, 3 in the last year and many more than that throughout Europe. The most infamous and active terrorist groups around the world are described as Islamist, groups such as ISIS, Al-Qaeda, Boko Haram and many more. There are over 100 verses throughout the Qur'an condoning violence of some sort and there is certainly no escaping that Islam has at least something to do with global terrorism. It therefore seems as though Islam is not only an outdated religion, but dangerous to modern society.

What must be understood here is that the Qur'an is not just a religious, spiritual scripture, it is a practical book; much of it is a response to different situations at the time, for example situations concerning marriage or food, and this includes verses allowing warfare and military action in certain limited contexts, and it is a

minority who wish to take it out of context. These verses are often taken out of context, not just their historical context but their linguistic context. These verses, by virtue of being a response to a certain situation are meant only for that context, and it is unfortunate that many Muslim extremist groups take these verses out of their context and wrongly use them as justification.

A prime example of a Qur'anic verse being taken and misinterpreted from its linguistic context is in Surah Al-Baqarah verse 191 which reads "and slay them wherever you catch them, and turn them out from where they have turned you out, for (Fitnah) is worse than slaughter". A problem with translating Arabic to English is the trilateral nature of Arabic root words, which can cause several different translations of words. Most commonly 'fitnah' is translated as persecution or oppression, in which case the verse is perfectly harmless. However, some choose to translate fitnah as disbelief, in which case the verse is calling for Muslims to slay disbelievers, which is of course how many extremists choose to interpret this. I would suggest that the former translation is the right one; not only does the latter translation contradict everything else in the Qur'an pertaining to peace and freedom of religion, but also there is significant evidence to suggest that the original translation and thus the purpose of the word Fitnah at the time of revelation, was as persecution and oppression, thus the verse cannot justifiably be said to incite violence.

Verses are more often taken out of their practical and historical context than their linguistic ones. To exemplify this point, you can take the verses that the Lee Rigby killers quoted in their letter in 2013. The main justification lay in Surah At-Tawbah, which is where the majority of the verses quoted came from. Lines such as "fight and slay the pagans wherever you find them" and "Go forth, whether light or heavy, and strive with your wealth and your lives in the cause of Allah" clearly justify violence. What is left out here is their verse and specific limited context historical context. This surah was revealed at the time of the battle of Tabuk, thus the context of these verses is in the context of battle; they are not universally applied and cannot be applied outside of the battle situation. When the verse states 'slay the pagans', the pagans are the people of Tabuk, not pagans or disbelievers in general, thus the Lee Rigby killers have absolutely no justification in these verses for their actions. This again demonstrates that it is not Islam that is the problem, rather the so-called Muslims interpreting them.

Terrorism is caused by political reasons rather than religious motives. Professor Robert Pape of the University of Chicago, one of America's leading terrorist experts, studied every case of suicide terrorism from 1980 to 2005, 315 cases in total, and came to the conclusion "there is little connection between suicide terrorism and Islamic fundamentalism or any of the world's religions, rather what all suicide attacks have in common is a specific secular and strategic goal to compel modern democracies to withdraw military forces from territory that the terrorists consider to be their homeland". Moreover, Gallup conducted the biggest poll of Muslims around the world, researching Muslim attitudes to 9/11. In doing so, they interviewed 50,000 people in 35 countries and found that 93% of Muslims condemned 9/11, and of the 7% that didn't, when studied and focus grouped all stated political reasons for their support for violence, not religious reasons.



CONCLUSIONS

It is clear from this that there is no justification for the claim that Islam is an outdated, discriminatory, violent religion; rather, there is an issue with the small minority of Muslims who wish to interpret it this way, namely the global Islamic extremist groups and to a large extent the law makers in Saudi. The very thing that caused Wahhabism and Salafism (ultra-conservatism) throughout the Middle East is up for debate, and I would argue geo-political reasons. As for global terrorism, a study done by The Telegraph showed a strong link between a lack of education in Pakistan and extremism; it seems therefore that a lack of education in countries throughout the Middle East and Asia, coupled with extreme political views, is the cause of modern day terrorism. I would argue that the Qur'an contains the solution to the problem of how to interpret religious texts within it when it calls anyone who cherry-picks uncontextualised verses 'perverse'. Seeing as the Qur'an is the divine word of God, there can be no flaws, errors or contradictions. I would argue that to cherry-pick verses about women and homosexuals and violence and

to then implement laws or actions that are misogynistic, homophobic or violent is completely contradictory with the rest of the Qur'an, calling for equality, peace and 'the middle way'. To argue that the Qur'an orders discrimination or violence is in complete contradiction with the peaceful nature of the Qur'an. In this instance, either there are in fact huge contradictions in the Qur'an, in which case it is not the divine word of God, or the verses are not meant to be interpreted in such a way and there are no such contradictions; I would argue the latter. This shows that violent, discriminatory interpretations of the Qur'an are illegitimate and self-contradictory and so have no justification, therefore should not be enacted or followed. As for the question of whether Islam needs a revolution, similar to that of Christianity, I argue not. It seems to me as though Islam can be rather easily applied to modern culture: the large majority of the 1.8 billion Muslims around the globe manage it, and as long as the core principles of Islam are kept intact, Islam can fit around modern society rather comfortably.



Simulating the propagation of light modes through photonic crystals in order to find correlations, focussing on the significance of the band structure

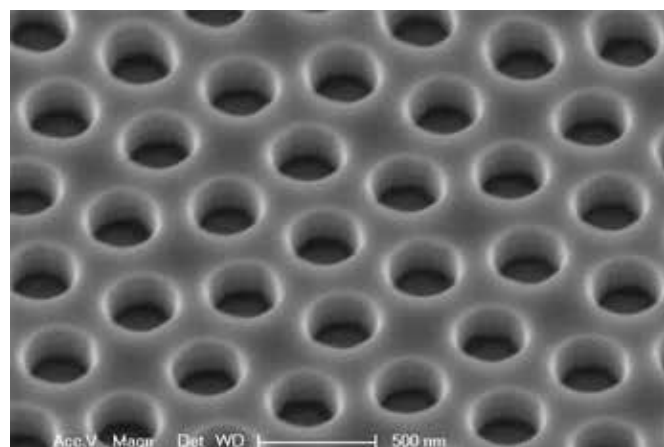
Jack Lee, supervised by Dr Marian Florescu of the University of Surrey

ABSTRACT

The aim of this project was to simulate the intricacies of how light interacts with and flows around different photonic crystals utilising two programs designed by a team at MIT, Meep and MPB (1), and to observe trends in their behaviour. A lot of time was spent on looking into how well the band structure, the available modes of light that can travel through the crystal, can explain all of the crystals' other properties.

INTRODUCTION

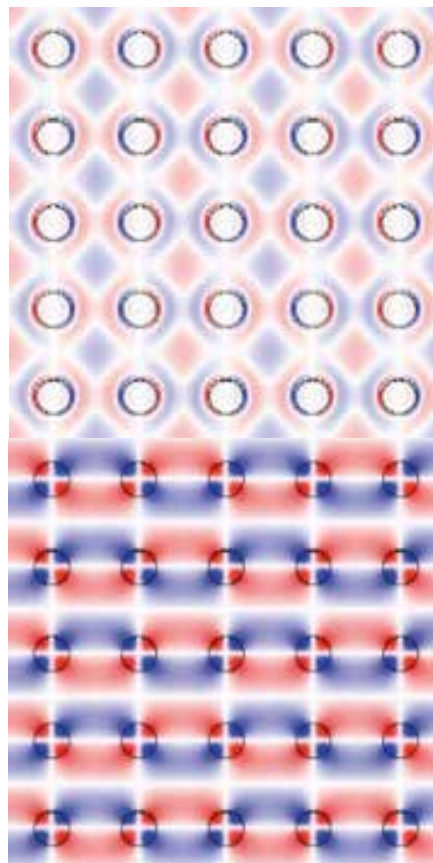
Photonic crystals are periodic arrangements of rods of a material or holes in a material that can cause light passing through it to interfere and create effects that are not observed in normal materials, such as total reflection and displaying an apparent negative index of refraction (2, 3). Quantum photonics is a cutting edge field of research, and is about understanding the crystals to use them for applications such



as more efficient optical fibres (using total reflection to keep the light confined) (4) and making components such as transistors that work with light rather than electricity. Using photonic crystals is not the only way to manipulate light, but it has certain advantages over its competitors: for example, it's easier to manufacture than techniques that revolve around manipulating light through molecular structure, as the photonic crystal's size must be of the order of magnitude of the wavelength of the light it's trying to influence, whereas other techniques require structure at a much smaller length scale.

STATIC MAGNETIC FIELD DIAGRAMS

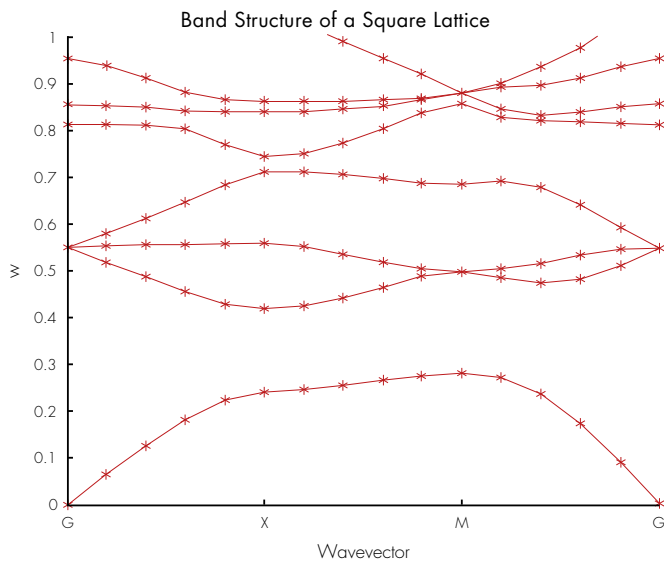
The first program I used, Meep, works by modelling a crystal that you specify and working out what modes of light can exist in it: these pictures show some of my results. The black circles show the position of the rods of material with a high refractive index, in this case arranged in a square lattice. The red parts show where the magnetic field is currently strong, and the blue parts are where it would be strong half of the wave's time period later. Some of the modes are centred around the rods, as the top mode is, whereas others are centred around the gaps like the second one. The first type is lower in frequency, as the wave spends more of its time in the material with the higher refractive index, which contributes to the curving near band gaps within the band structure. An additional aspect is the polarisation of the light: these modes both appear with transverse magnetic (TM) light, which is when the magnetic field is perpendicular to the plane of the crystal, and the modes appearing are completely different to transverse electric (TE) light.





PHOTONIC CRYSTAL BAND STRUCTURES

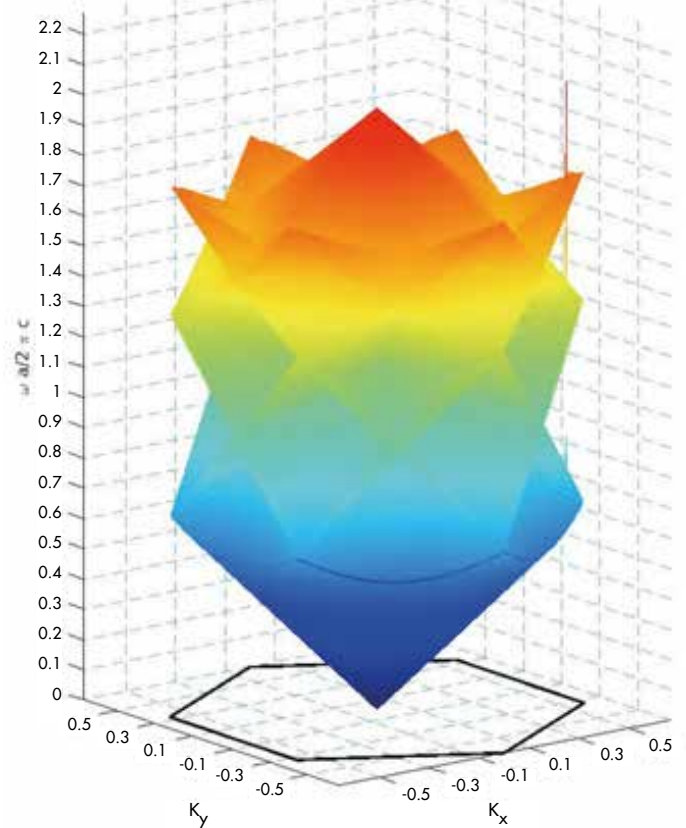
A band structure is a graph, such as this one, which shows what frequencies of light can enter the photonic crystal from each direction. This graph is made by looking at a version of the crystal that has undergone a Fourier transform (that is, a mathematical construct that is related to the crystal but easier to analyse), taking the smallest repeating unit of it (the irreducible Brillouin zone), and then looking round the edge of it to see what frequency the light can be at each point (5). Each line of points represents a mode, such as those shown previously. Another significant part of the graph is the band gaps, which are the values of ω (the frequency) where there is no corresponding wave vector: these are frequency values where light is totally reflected due to interference (6). Again, this is a TM graph, and the TE graph will be completely different, so for a crystal to have a complete band gap in 2D for a frequency (i.e. no light can pass regardless of the polarisation and direction) then there must be an overlapping gap in both graphs.



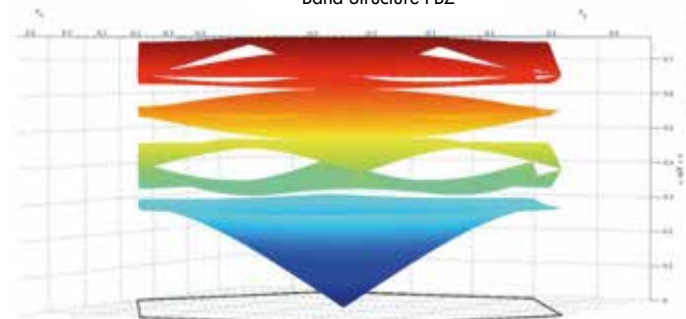
The next diagrams will be 3D band structures: these show not just the edge of the Brillouin zone, but the distribution of frequencies over the unit cell. This diagram here shows the unit cell for a crystal that is almost completely air: you can see how it is entirely continuous, as light can pass through air at any frequency. In SI units, the gradient of this line is c (or $-c$, as it is bent artificially to stay inside the graph) as the equation $\omega = ck/n$ was how Maxwell originally derived c . The exception to this are the spikes near the top, which are caused by the small amount of crystal.

In contrast to the air band structure, these ones are for a triangular based crystal made of gallium arsenide (GaAs). You can see that this is a lot less continuous, with a clear band gap between the first and second bands where, as before, no light will be able to enter from any direction. An additional interesting comparison is the curvature of the bands: coming up to the band gaps, you can see that the bands curve to 0 gradient. Because the gradient corresponds to c/n , this means that the crystal can really have any refractive index that is desired by selecting the correct frequency of light. Additionally, you can see that some of the bands have a negative gradient, coming in to the middle: this leads to the phenomena of negative refraction, as it implies a negative n .

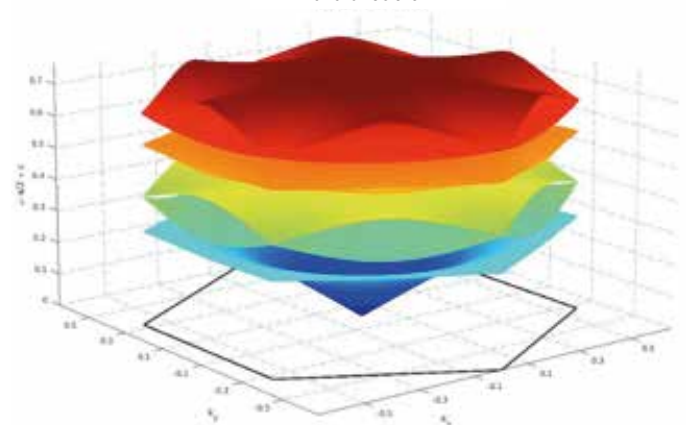
Band Structure FBZ



Band Structure FBZ

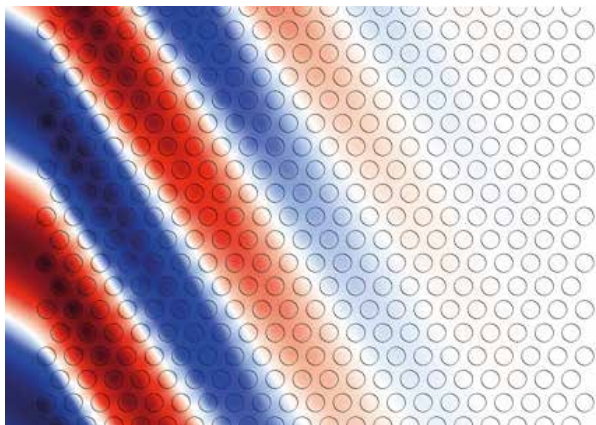


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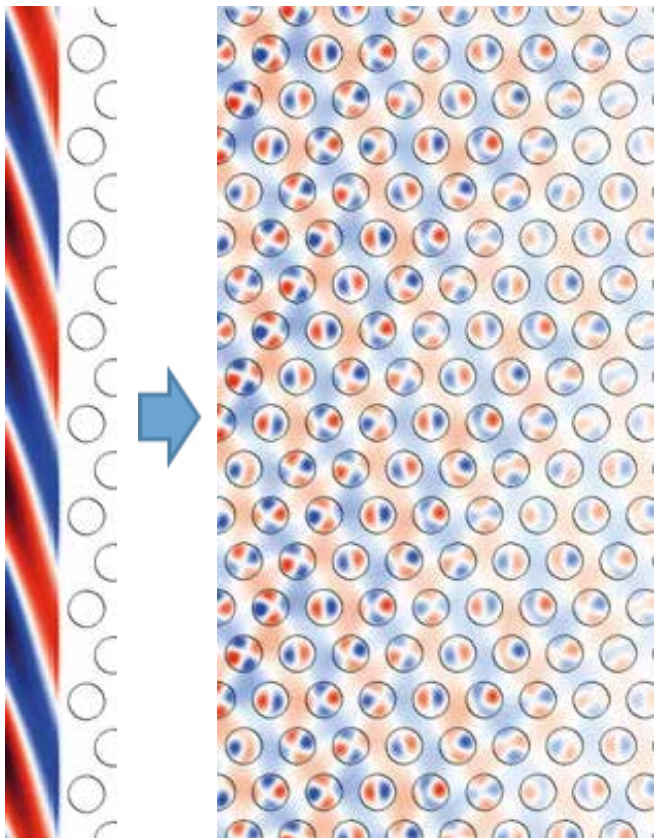


FINITE DIFFERENCE TIME DOMAIN SIMULATIONS

Before I talk in more detail about negative refraction, however, I'll inform you about the system I used to simulate it, Meep. This is a finite-difference-time-domain (fdtd) simulator, and works by sending a range of frequencies into a crystal and modelling what happens to them: this is in contrast to the previous simulations, where I had modelled every different frequency that could appear in the crystal. This picture is from an fdtd simulation for ordinary refraction: the direction of the wave's propagation is perpendicular to the individual wave fronts,



and you can see that it bends towards the normal as it enters, and will return to its original orientation when it leaves again. The top and bottom edges of the space are modelled as being a continuation of the crystal, whereas the two sides are perfectly absorbent, mimicking an open room. On the band structure, this effect appears where the

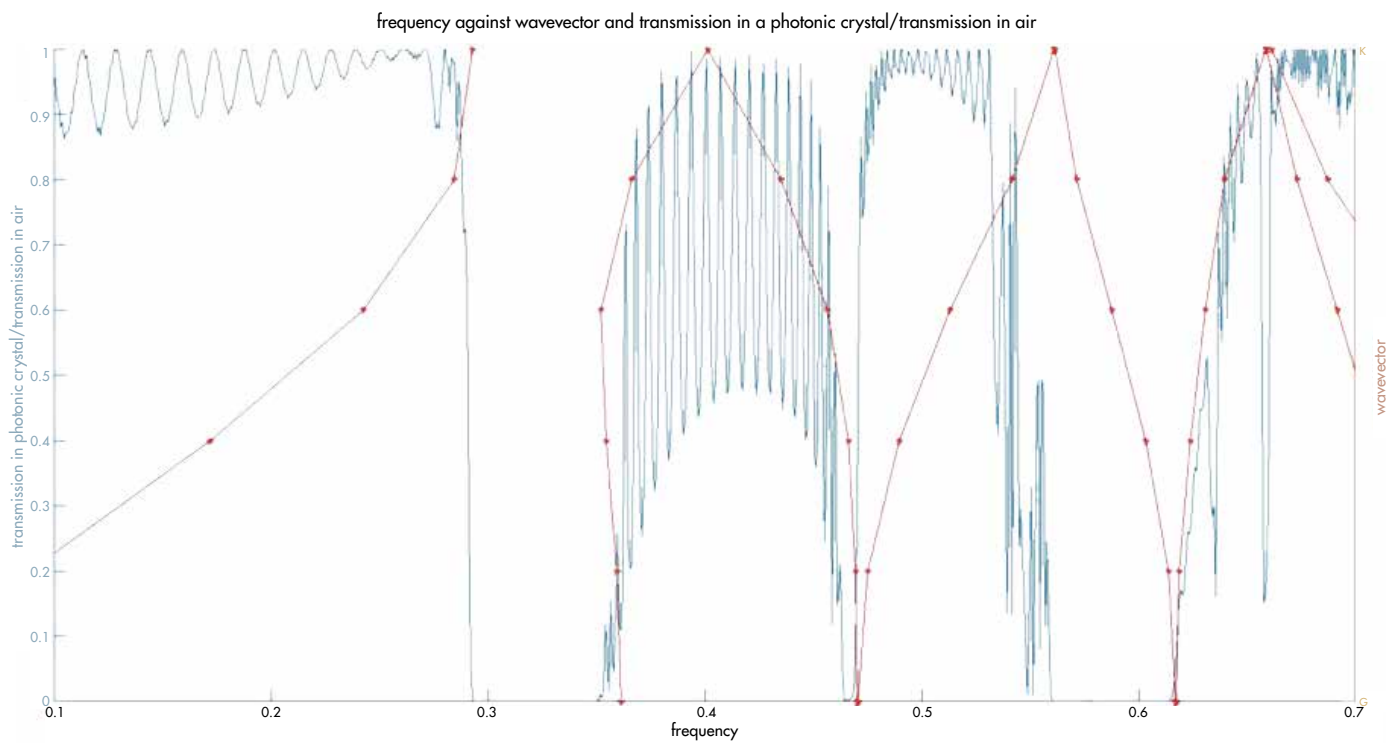


gradient is positive and the cross section is circular: this is because a positive n is required, and light must behave in the same way when approaching it from all directions for the crystal to be properly said to have a refractive index (7).

In contrast to this normal refraction, therefore, is the negative refraction shown here. The wave comes up to the crystal as before, and although the orientation of the individual wave fronts doesn't change by too much, the entire wave starts to propagate downwards. This difference from the previous refractive index occurs because this is an effective refractive index rather than an actual one: the light is not actually going at a negative velocity, it just appears to be. There are several uses for this: for example, a negatively refractive material can be used to create an image of an object through the same translation as a mirror would provide, but one that is real and 3D rather than a virtual one. This image can also theoretically be more precise than the mirror's, as the mirror is limited by different factors to the crystal.

COMPARISON BETWEEN THE BAND DIAGRAM AND TRANSMISSION SPECTRUM OF A PHOTONIC CRYSTAL

The final part of this discussion will be comparing the transmission of a photonic crystal (i.e. how much of each frequency of light emerges at the right hand side) with its 2D band structure, similar to the one shown earlier. The graph above shows this for a triangular lattice photonic crystal made of GaAs: frequency is on the x axis, and then the left y axis (for the transmission) shows the transmission for the crystal divided by that of air (for calibration), whereas the right y axis shows the wave vector for the band structure. Unlike in the previous band structures, however, the light is only incident from one direction and so only one side of the irreducible Brillouin zone is relevant. You can see that for all frequencies where there is transmission, there is an available band for the light to travel through, as you'd expect. However, there are several interesting parts of the graph: for instance, the strange nature of the transmission line, which has consecutive peaks and troughs rather than being flat. This occurs because of interference between the main light wave and reflections off the rods: depending on how the distances work out, the reflections can either constructively interfere when they reflect back and re-join the main wave, almost removing the loss caused by the reflecting completely, or interfere destructively, magnifying it, or do anything in-between. You can see that for low frequencies ($\omega < \text{about } 2.8$) this reflection is the only real source of loss, so that in places the transmission in the GaAs is the same as that in air in places, but that later on the more macroscopic interference in the crystal becomes apparent and the transmission drops further. Additionally, the frequency boundary at which this occurs can be tailored by altering the length scale at which the crystal is periodic to approximately match the wavelength of the light that you want it to affect. The final feature of note is the area between $\omega \approx 0.57$ and $\omega \approx 0.62$, where there is a band present but no transmission is able to occur. This is due to the symmetry properties of this particular band forbidding any transmission at all at this specific angle of incidence: however, if the light were to approach just off centre then we would see transmission here.



CONCLUSIONS

Overall, therefore, we can see that there are several interesting trends relating the various properties of photonic crystals: in particular, their band structures help to explain many behaviours of them such as how light will refract through them when approaching from different directions and which frequencies of light are allowed to pass through. However, there are some aspects that the band structure does not inform us about, such as the issue with symmetry properties highlighted by the last example. Additionally, the band structure does not tell us how much light will be transmitted by the crystal where there was transmission, and it did not give any indication of the waves of transmission occurring due to reflection within the crystal, nor did it tell us anything about the nature of the modes, which can be useful for isolating them with imperfections in the crystal. Although the band structure tells us several very useful pieces of information, it seems that it does not give the full range of details required to use the crystals smoothly, and that as such the other simulations remain significant.

ACKNOWLEDGEMENTS

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The best way to ensure affordable housing and a strong economy across the UK

Winner of the Fitzwilliam College Cambridge, Land Economy Essay Competition 2017

Matthew Leslie

The best way to ensure affordable housing and a strong economy across the UK is to subsidise job creation in the North of England, thereby reducing demand in London and stimulating the regional economy. Discuss.

There is an important distinction to be made, between results (accomplishing affordable housing and a strong economy) and method (reduced housing demand in London and a stronger regional economy). The extent to which subsidising job creation is an effective policy therefore somewhat depends on its ability to fulfil its objective in this way.

A key term to address is a *strong economy*. McKinsey (2015), whose research has examined past economic performance and prospects for the future, describes GDP as 'the most widely available and commonly used metric'. Indeed, many countries continue to use GDP as a key macroeconomic indicator for strength of economy. However, there is also a need to acknowledge and address the tough trade-offs that come with encouraging growth, particularly to the environment, income inequality, and the trade balance. Other indicators have been used to evaluate the strength of an economy, including the exchange rate, inflation, unemployment, and the fair distribution of income. Stiglitz et al. (2010) advocate broader measures of economic success taking in environmental impact, a macroeconomic objective in significant conflict with growth, and the impact on social well-being. Nevertheless, GDP remains a reliable indicator of the strength of an economy, perhaps because it is the most easily compared between countries with different economic priorities. This does not mean GDP should be the only measure of economic strength, and furthermore, the figure of growth for the UK as a whole does not identify the disparities in growth rates across regions or sectors of the economy. Perhaps most significantly, GDP figures cannot identify whether growth is sustainable, including for the UK housing market.

The other key term in this question, *affordable housing*, has a number of interpretations. The UK government's definition of affordable housing for planning purposes is (Department for Communities and Local Government 2012):

"Social rented, affordable rented and intermediate housing, provided to eligible households whose needs are not met by the market. Eligibility is determined with regard to local incomes and local house prices. Affordable housing should include provisions to remain at an affordable price for future eligible households..."

Importantly, this definition refers to rented accommodation, and does not include homes for purchase, an important component of housing

affordability to take into account. If prices for homes to purchase are not affordable, people may become stuck in the rental market, with no effective alternative. As more people remain in the rental market, crowding may occur, and as excess demand continues to drive prices up, rents become even less affordable for people unable to purchase.

The homelessness charity 'Shelter' (2015) have pointed out that affordability varies widely between households and their different circumstances. They suggest as a guideline that spending 35% of net household income on rent or mortgage should be treated as the limit of affordability.

Research at Nuffield College (2016) has shown that rents have increased in recent years, in a large part due to the increasing cost of house purchases: 'The declining affordability of home ownership restricts many households to the private rented sector, and over the past 15 years, the number of people living in privately rented properties has increased considerably. This proportion nearly doubled from 8.8% in 2001 to 15.4% of all English and Welsh households in 2011, and by 2013–2014 comprised 19.4% or 4.4 million households in England.' This pressure on the rental sector has pushed rents upwards as a result. Furthermore, the gap between least affordable and most affordable housing regions in England and Wales has increased over the last two decades, and taking the charity 'Shelter's' definition of the term, this now means that a considerable number of houses are unaffordable to purchase.

However in broader terms, the gap in affordability between the 'North' and 'South' of the UK has actually reduced from the early 1990s onwards. Housing costs have risen faster in Scotland, the North West, North East and Midlands compared with the South East. Yet the standout region that does not follow this trend is London. Over the last 20 years, the proportion of their annual income that Londoners spend on housing has risen by over 50%, from 17% to 28%. The average housing cost to income ratio (HCIR) in London is 6 percentage points higher than the area with the next highest ratio, and 11 percentage points higher than the North East (Department for Communities and Local Government 2015). While there seems to be a general trend of a reducing affordability gap between the North and South of the UK, London is an exception.

With trends in affordability somewhat conflicting, it is important to recognise that there is no clear consensus on where the problem in affordable housing lies. A number of people have pointed to a lack of new housing supply as a significant reason for excess demand growing, hence leading to rising house prices and less affordable homes, both to rent and purchase. In 2004, Kate Barker reported to the Government that not only did rising



house prices reduce affordability, but they also restricted labour mobility, and had the effect of redistributing wealth from non-home owners (and first time buyers) towards those who already own homes. Ms Barker asserted that the number of new homes built each year (then about 125,000 across the UK) should be increased by between 70,000 and 120,000 in order to correct the imbalance between demand and supply and slow house price inflation. On the other hand, Ian Mulheirn (2017) suggests that the housing problem in the UK is not caused by a housing shortage, but rather the ineffective allocation of existing housing, specifically concerning the issues of homelessness, a shortage of social housing, and cuts to Housing Benefit. Mulheirn asserts that the number of households in the UK has been growing by about 152,000 a year, and construction of new homes (roughly 174,000 a year on average) exceeds this; hence there is no problem of overall supply.

Douglas McWilliams (2017) accepts Mulheirn's evidence that 'for the UK as a whole, market rents have plateaued. And that technically the number of houses have increased faster than the number of households.' However, McWilliams identifies two problems with Mulheirn's argument: while on paper there may be enough houses, not all are structurally sound, and there are 'surpluses of houses in places where people do not particularly want to live'. In McWilliams' view, the housing shortage is localised, and specifically in London, which now has a deficit of 123,000 homes. This increasing scarcity of housing has caused prices in the capital to rise by 350% in the last 20 years – 'the excessive cost of housing is by far the single largest driver of inequality in London', McWilliams asserts.

Taking into account both Mulheirn's and McWilliams' views, there is perhaps a need to address:

- a) the problem of excess demand in priority areas as indicated by high rent and mortgage prices, thus increasing the affordability of housing in high-demand areas, and
- b) to incentivise investment in viable regions, making available, affordable areas of housing more attractive for home-searchers to move to.

Subsidisation of job creation is a proposed policy to tackle the problem of affordability and promote a stronger economy, and this form of subsidy is designed to increase the level of employment by encouraging firms to take on unemployed workers. Some job creation schemes, such as the New Deal introduced by the Labour Government in 1998, have led to positive results. John van Reenen (2001, 2004) concluded that the scheme should continue, as it had increased the chances of unemployed men getting a job by about 20%. However it is important to understand the cost and political circumstances of Labour's New Deal. The Labour Government had won an overwhelming majority in 1997, and costs for the project were funded through a one-off £5 billion windfall tax on privatised utility companies. While the policy may have achieved its objectives, it was both expensive and unpopular with taxed firms. Labour were able to capitalise on strong political support for the policy, a circumstance unlikely to reoccur, or on the same scale of investment.

Aside from costs and political popularity, job subsidisation may not be effective in the long term for achieving a net increase in the level of employment. Stephen Smith (2003) concludes that 'policies that subsidise private sector employment appear to suffer from substantial deadweight and substitution effects', quoting an evaluation of wage subsidy programmes in Australia, Belgium, Ireland, and the Netherlands that

suggested that for every 100 jobs subsidised by such schemes, only 10 were net gains in employment. Subsidising jobs in the North of England may lead to a reduction in the unemployment rate, but the dangers of substitution and deadweight loss could mitigate its effectiveness.

Job creation does present an option for achieving a stronger economy, but opinion seems to be divided as to whether this would be a cost-effective policy, and more importantly, whether subsidisation on a feasible scale would necessarily have the effect of reducing demand for affordable housing in London. Historically, there has been a longstanding UK dependence on, and investment in, financial services centred around the capital, rather than in productive industry. The overheating of the London economy is the inevitable result – Larry Elliott of the Guardian (2017) sees London's economic activity as representative of the UK's wider role in the single market, and involves an element of international division of labour: 'Germany is best at precision engineering; Britain is best at finance and so has acted as the merchant banker for the rest of the EU. That has made London extremely rich, but widened the gap between the capital and the rest of the country.' As London continues to have a gravitational pull on those seeking work and wanting to set up businesses in the UK, the prospect of job creation elsewhere – particularly with the aim of creating affordable housing – attracting London home-searchers seems relatively slim.

Realistically, additional measures to job subsidisation in the North are needed if demand for affordable housing in London is to reduce. A number of government initiatives have aimed to rebalance the UK economy by spreading economic activity away from London and towards other regions. Regional Development Agencies (RDAs) were established in 1999 in nine regions of England with the aim of encouraging investment and stimulating economic development. In 2011, after the abolition of RDAs, the Government's Plan for Growth set objectives that included 'an increase in private sector employment, especially in regions outside London and the South East'. In its Northern Powerhouse strategy, the Government committed to investing in transport links and research, as well as to devolving powers to mayors elected in the larger cities of the North. David Prosser (2015) argues that the problem lies with regional management being poorly cooperated and collaborated on. He urges that the UK needs 'a strategy that brings all the initiatives together - not under a scheme run from Whitehall, but via regional bodies that are capable both of leasing with one another and building local structures designed holistically according to what is needed on the ground.'

Other measures to promote regional economic growth might include tax incentives for export businesses, subsidising job training, and giving businesses "free or highly subsidized advice on how to improve their productivity or product design, and how to find new markets" (Bartik 2011). Gregory (2016) suggests that investment in infrastructure and skills are important ways to promote the regional economy.

In conclusion, allowing London to expand fulfils goals to do with affordable housing and GDP, but in terms of England's interests as a whole, the problem of inequality, specifically London compared with the rest of the UK, must be addressed. Subsidising job creation on its own may not be an answer to the problem, but combining this with a range of other measures may prove successful in both addressing the imbalance between supply and demand in highly expensive housing areas, and stimulating regional economies to help redistribute affordable housing demand away from London.



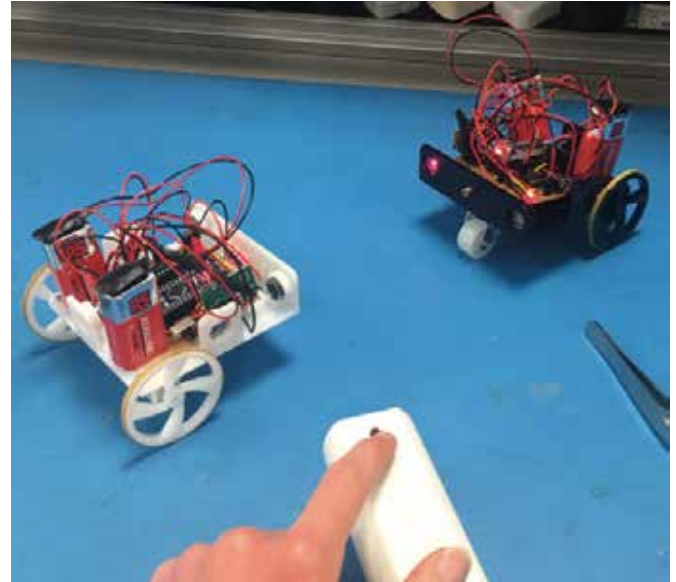
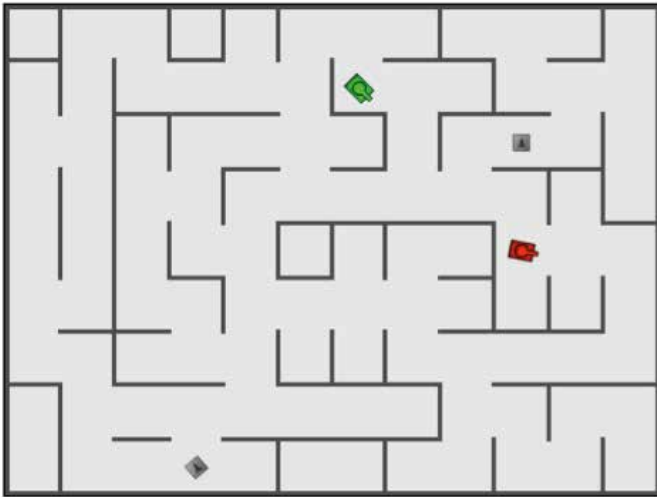
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Tanks in real life

Oren Hargreaves, supervised by Dr Radu Sporea of the University of Surrey



OVERVIEW:

INTRODUCTION:

My project brief was to build an Applicant day Arduino sensor project. When I received this project I knew that it would be very open ended and I felt inspired to create something that a prospective student like myself would find interesting, interactive and most importantly display Arduino and its open ended capabilities.

BACKGROUND:

I was offered this project by Dr. Radu Sporea who acted as my supervisor. He is in charge of the open days for the Electronic Engineering department at the University of Surrey. As such he wanted a project which students visiting the department could interact with.

BACKGROUND WORK:

Before coming to do my project I looked into Arduino and the numerous companies which have sprung up around the company offering a variety of sensors. This involved looking online for project ideas. My main way of looking into this was through instructables.com. This is a hobbyist website where people post projects that they have completed, often with a full write up, making them easy to follow along.

RESEARCH:

INITIAL IDEAS:

On instructables.com I looked through the Arduino portion of the website in order to understand what would be achievable with the time and resources I had. (All photos shown are from the full article.)

SELF BALANCING ROBOT:

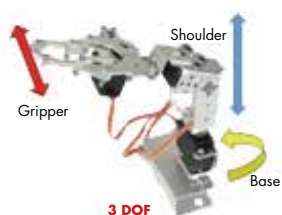
Through the use of accelerometers and gyroscopes the angle of the ground to the robot is calculated and the motors turn on to move the robot upright. The system is constantly correcting itself and can even sustain being pushed. The project was by Pinuct and the full write up can be found here: <http://www.instructables.com/id/Self-Balancing-Robot/>



I thought this project was a nice concept and would have introduced me to a type of sensor I had no experience with. However it would not be very actively engaging to prospective pupils at an open day. Furthermore I thought it would be too simple and would not take the full period of time.

PROGRAMMABLE ROBOTIC ARM:

By using servo motors this project allows for a robot to be made similar to the large scale ones in factories. The version here can be controlled through three axes, which is fewer than the six or seven seen in factory versions. The project was by MertArduino and the full project write up can be found here: <http://www.instructables.com/id/Arduino-Programmable-Robotic-Arm-Record-and-Repeat/>



This project would have been simple and at an open day it would have been interactive. However I do not think it would have taken very long and would have been too simple, therefore not showing off the Arduino system to its full capabilities.

ROBOTIC HAND:

This project was a low cost, cheap and cheerful attempt at simulating a prosthetic through the use of a glove interface and wireless technologies to control a model hand. The controller is a glove with flex sensors fitted. The commands are sent over Bluetooth to the robot hand where servo motors control the extension and contraction of the digits. The project was by MertArduino and the full project write up can be found here: <https://www.instructables.com/id/Arduino-Make-a-Low-Cost-Robotic-Hand-With-Wireless/>



This project would have been very fun and I think that it would have resonated with people at an open day as they could see how basic electronics skills could lead to real world applications and how they could help other people. However in the conclusion of the write up it comments that the system was not very reliable and that more expensive sensors would probably be the best way to improve this.

ARDUINO XYLOPHONE:

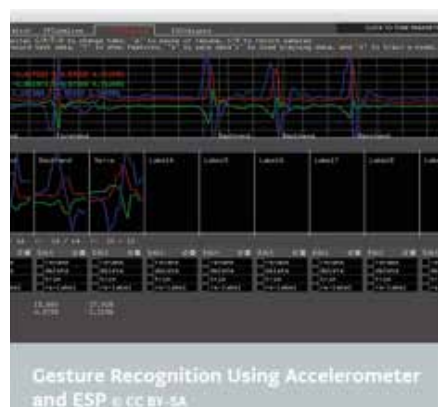
This basic project uses piezo transducers to detect vibrations on the keys. The system is then put into an application on the computer such as GarageBand so that you can record music. The project was by AudreyObscura and the full project write up can be found here: <https://www.instructables.com/id/Arduino-Xylophone/>

This project was very simple due to most of the work already being done for you by GarageBand.



GESTURE RECOGNITION TO CONTROL . . . :

The idea behind this project was to introduce some software that the author had written which used machine learning to recognise gestures sent to the software through an Arduino. The software would then send back a signal depending on which gesture is detected allowing for you to control all sorts of things in a novel way. The project was by Ben Zhang, Bjoern Hartmann, Nick Gillian and Audrey Leung, and the full project write up can be found here: <https://create.arduino.cc/projecthub/mellis/gesture-recognition-using-accelerometer-and-esp-71faa1>



Through this software I believe I could make a system that could control some sort of game where prospective students could interact fully. In this way the system fulfils the brief. Furthermore the open sided nature of this application leads to the possibility of combining some of the previously mentioned projects to create something new.



METHOD:

EQUIPMENT/SOFTWARE:

ARDUINO:

Arduino is an open sourced product designed as a low cost way for hobbyists to interact with the real world electronically through the use of sensors and actuators. Arduino also offer free software in which you can write your own code to run on the device. There is a large community of makers on the internet who have provided many application programming interfaces and instructional materials to help anyone learn. The functionality of the board can be further expanded through the use of shields. These slot onto the Arduino through the pin headers on the Arduino.



Image from cortexdynamo.com

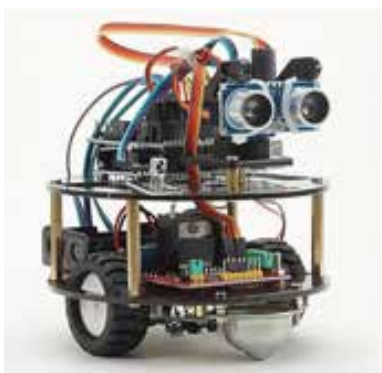
We bought a starter kit off Amazon for under £50 which would include all of the sensors and components needed to explore our initial ideas. The kit came with an ultrasound sensor and we hoped it would be the basis of our project. Throughout the days at Surrey we hoped that we could get a basic prototype up and running to test the feasibility of using Arduino as a controller for the project.

Arduinos are mainly programmed using C and C++ which are common programming languages. With basic programming knowledge and some time anyone can quickly pick up the necessary skills to try out a project idea.

The main value of the Arduino is the online support and community, who can help with the trickiest of issues. Most sensors come with their own library and example code, making programming them much easier.

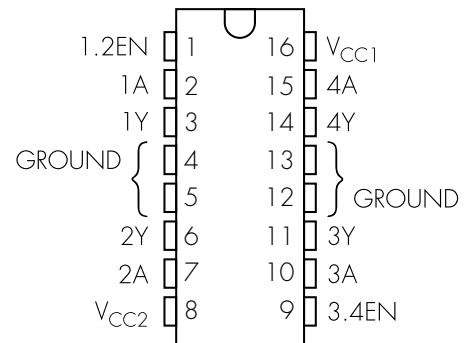
While programming the Arduino it must be connected to the computer via a USB cable; however once programmed it can run off mains electricity or battery power. Data can be easily transmitted through the Bluetooth module or Ethernet module.

At the high end, Arduino has almost unlimited functionality. It can be used to make and control a 3D printer, a robot, a drone or even control a smart home.



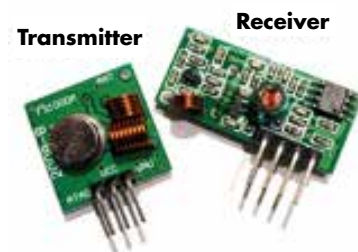
L293D MOTOR CONTROLLER IC:

The L293D [1] is an integrated circuit acting as an interface between a microcontroller such as an Arduino and the motors. The chip is necessary because it makes controlling the motors easier and easily allows the motors to have their own power source. This is important because in the case of the motor drawing too much current, it will not turn the Arduino off.



433MHz TRANSMITTER/RECEIVER:

These [2] Arduino compatible modules are one of the easiest and cheapest ways to add wireless functionality to a project. With the use of a compatible Arduino library such as VirtualWire [3] you can send commands reliably across the room. By adding an antenna (a piece of wire) the range can be extended to go through thin walls.



ADXL335 ACCELEROMETER:

This accelerometer [4] is a low power Arduino compatible three axis accelerometer. Two out of the five pins are connected to power and ground and the remaining three are connected to the analog pins of the Arduino. They send data about the position and movement of the three axes of the pin. Through clever software, one can take these data and infer movement of the sensor as a whole, allowing for it to be used as a control mechanism.



LDR:

Light dependent resistors (LDRs) [5] are a commonly used sensor. The resistance of the sensor reduces as more light is present on the surface. This allows for the light level of a system to be measured.

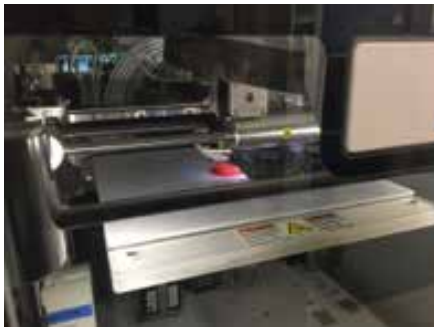


LASER DIODE:

A laser diode [6] is the underlying technology behind commonly found laser pointers. Laser diodes will be utilised to "shoot" the LDRs (acting as targets), reducing their resistance which can easily be recorded and acted upon.

3D PRINTING:

3D printing was used to quickly prototype the casing for the controller and specific parts of the tanks. These were complex objects with curved forms and features in multiple dimensions making other manufacturing techniques unsuitable.



LASER CUTTING:

This method is highly precise and very quick. After feeding the laser cutter a vector drawing it cuts it out of a sheet of plastic with precisions to fractions of a millimetre. Laser cutting is ideal for simpler, larger objects which are one dimensional.

SOLDERING IRON:

This is essential for any electronics work. It allows you to form conductive joints between two objects. In this project it was used to attach header pins and solder the prototyping board in the controller.

ONSHAPE:

OnShape [7] is free to use online computer-aided design (CAD) software. The main advantage of OnShape is its speed. Most CAD programs run directly on the computer, which is very intensive and requires a very good computer to run well. OnShape on the other hand is internet based, meaning the complicated part is handled by OnShape's servers. Furthermore it is free and has a simple interface.

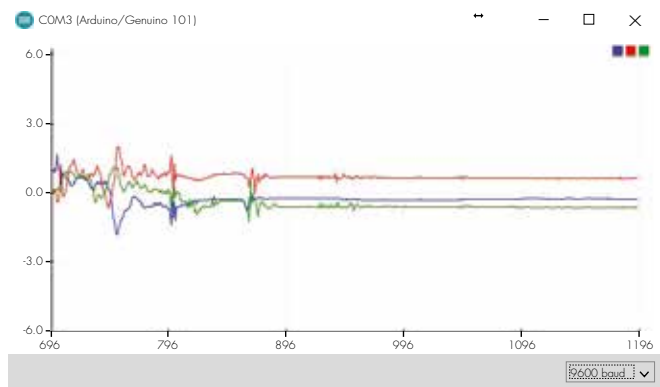
FRITZING:

Fritzing [8] is free to use software that lets you easily make Arduino schematics, giving you a PCB layout and breadboard diagram. I used this software for my project to help me know where to connect the Arduino and parts. The software also allows you to write the code for the Arduino, instead of using the Arduino development environment.

DEVELOPMENT CONTROLLER:

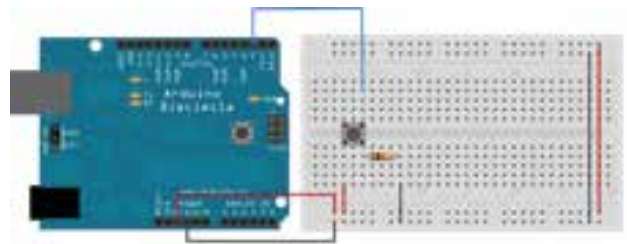
ACCELEROMETER:

The main control mechanism of the tank is the accelerometer. By tilting the controller left, right, forward and backward the tank will turn and move. To achieve this an accelerometer sensor is needed to measure movement. The X, Y and Z pins of the accelerometer are hooked up to three analog pins of the Arduino and the when the values of the accelerometers are printed to the serial plotter they show a trace like this, with minimum flat lines when the device is still and jagged ones when it is moved. By calibrating the sensors and through a simple algorithm, the program determines which direction the controller is tilted. This information can then be utilised to control the tank.



LASER BUTTON:

To shoot the laser a button is connected to the Arduino. The resistor ties the input to the digital pin to ground so that the pin is not triggered accidentally by noise. The trick to making the button function well in the program is to not have any delays, otherwise when the program is stuck in a delay it will not process whether the button has been pressed and therefore when pressed the action will not always be recognised.



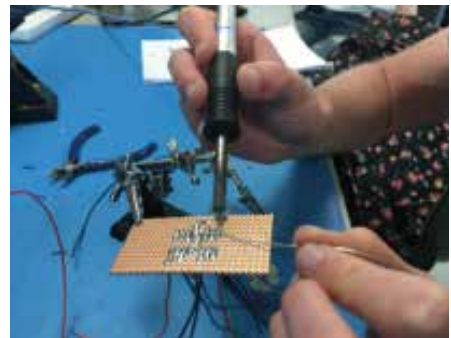
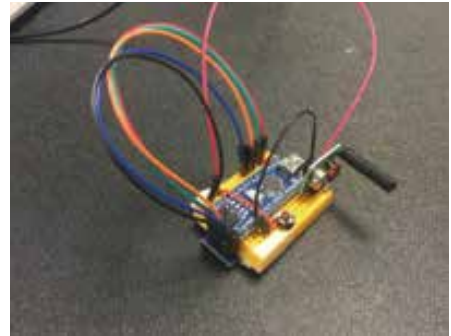


RF TRANSMITTER:

Once the accelerometer has determined the tilt of the controller and whether the laser button is pressed, this information then needs to be sent wirelessly to the second Arduino. To do this I used the 433MHz RF transmitter module. The pin out diagram is relatively simple, you connect the "VCC" pin to 5v, the "GND" pin to ground and the "ATAD" pin to a digital pin of the Arduino. To help me send messages I used the Virtual Wire library, which adds a few simple commands which allow you to send messages to a receiver.

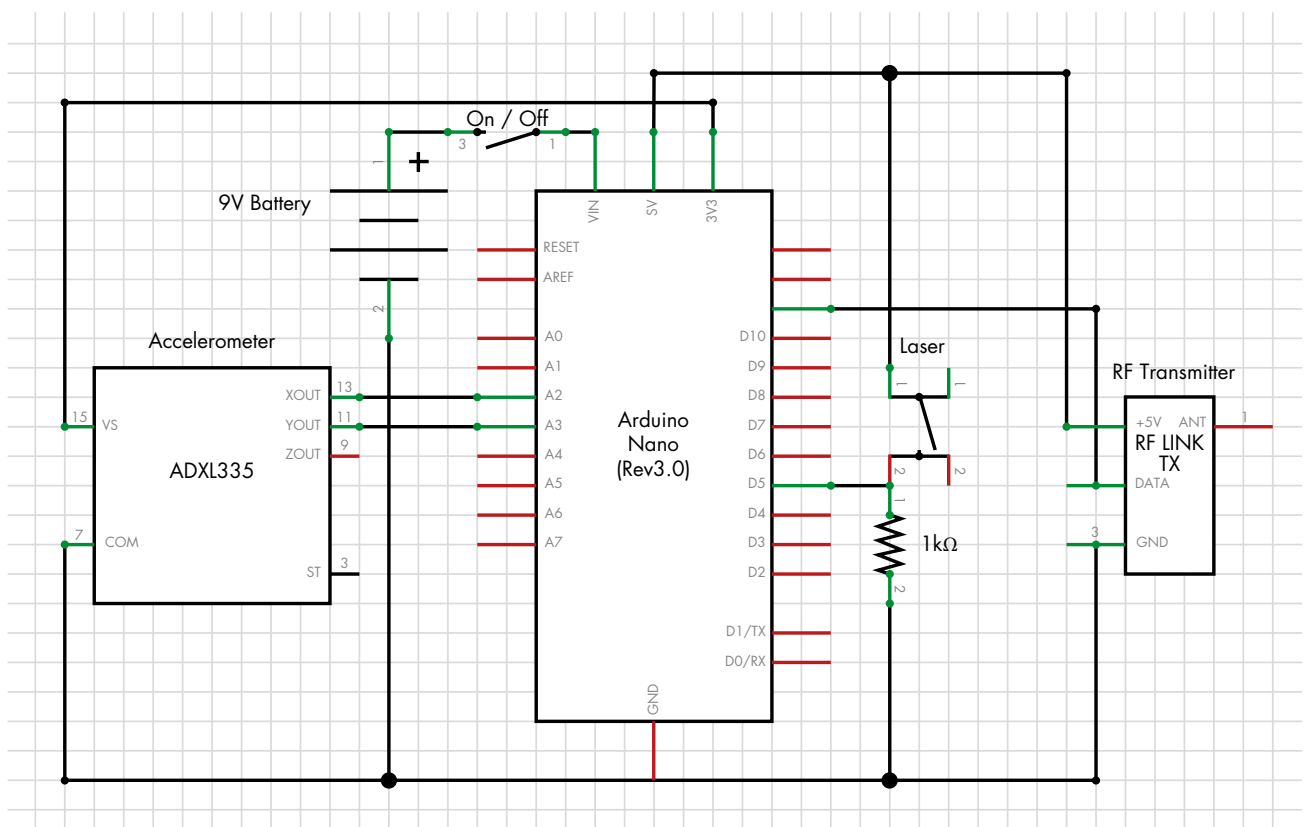


I decided to use a simple 9V cuboid battery since they were an off the shelf component and easily available. I decided to use breakout pins and DIL sockets so that the sensors and Arduino weren't physically attached to the board and could be removed and replaced. This all worked very well; however I further miniaturized it by removing the Veroboard and soldering everything together with jumper wires. While this is more messy it made it far smaller so that it fitted into the casing easier.



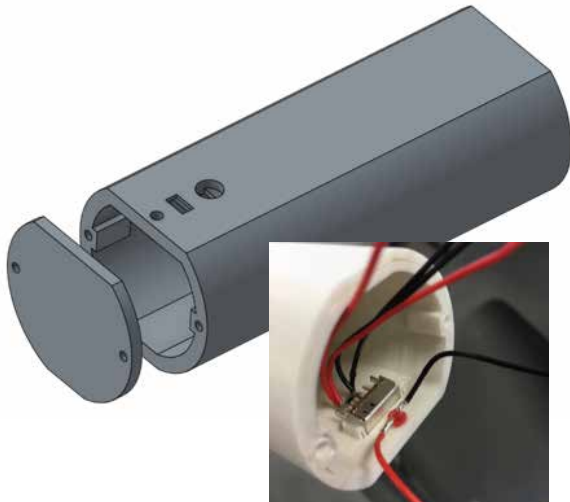
CIRCUIT:

The next stage of the process was moving the circuit, which at this stage was on a mini breadboard, to Veroboard. This was so that it could be made smaller and more compact, ensuring that the controller case could be made as small as possible, making it easier to use. To power the circuit



CASING:

After measuring the dimensions of the new circuit I used OnShape to create a 3D model. I wanted the controller to be comfortable to hold. On the outside there needs to be an on/off switch and the "shoot" button; other than that I wanted to keep it simple to use. Further considerations were flattening the cylinder on two sides so that it sat still on a surface and adding a lid which could be screwed into place.



```
buttonPressed();
shootLaser();
}
void getData() { // gets the raw data from the accelerometer
  xRaw = analogRead(xpin);
  yRaw = analogRead(ypin);
}

void baseline() { // finds the offset
  getData();
  xBase = xRaw;
  yBase = yRaw;
}

void calibrateData() { // removes the offset
  xValue = xRaw - xBase;
  yValue = yRaw - yBase;
}

void directionToGo() { // determines the orientation of the controller
  if (yValue < -sensitivity) {command = 1;} // forward
  else if (yValue > sensitivity) {command = 2;} // backward
  else if (xValue > sensitivity) {command = 3;} // right
  else if (xValue < -sensitivity) {command = 4;} // left
  else {command = 0;} // nowhere
}

void newMovement() { // checks whether the command is either new or it has been a while
  if (lastCommand != command || timeOfCommand + 1000 < millis()) { // since it was last sent
    timeOfCommand = millis(); // after command has been sent resets the timer to send another
    sendCommand(command);
    lastCommand = command; //resets variable
  }
}

void sendCommand(int c) { //sends message based on command variable sent in
  switch (c){
    case 0: movement("0"); break;
    case 1: movement("1"); break;
    case 2: movement("2"); break;
  }
}
```

PROGRAM:

The Gesture recognition software I had planned to use to work out the gesture the user was making was extremely temperamental and therefore I had to develop my own algorithm to determine the gesture. To do this I had to calibrate the sensor when it was turned on and then used a variable to determine the level which the sensor had to be tilted for the remote to send the command.

```
White_Transmitter.ino | Arduino 1.6.13
White_Transmitter.ino 5

#include <VirtualWire.h>

const int onLED = 6; // led is placed in case for user convenience
const int button = 5; // button to shoot laser
const int Tx = 11; //initiate all of the variables I'll need to store
const int led = 13; //the data for pin numbers and variables
const int ypin = A3; // accelerometer y axis
const int xpin = A2; // accelerometer z axis
const int sensitivity = 25; // variable which adjusts the sensitivity of the controller

int xValue, xBase, xRaw; // variables which hold the X data
int yValue, yBase, yRaw; // variables which hold the Y data
int buttonMode = 0; // variable to hold the button state
int command; // variable to send the direction command with
int lastCommand; // variable used to not send repeating commands
int timeOfCommand; // variable to only repeat a command after certain time

void setup() {
  Serial.begin(9600); // Debugging only
  Serial.println("setup");
  vw_setup(2000); // Bits per sec
  vw_set_tx_pin(Tx); //Transmitter Data Pin to Digital Pin 3
  pinMode(xpin, INPUT); //setting pins as Inputs / Outputs
  pinMode(ypin, INPUT);
  pinMode(button, INPUT);
  pinMode(onLED, OUTPUT);

  baseline(); // calibrates the sensors to a zero point

  digitalWrite(onLED, HIGH); // led comes on when calibration has completed
  // so the user knows it can be used
}

void loop() { //main loop goes through these functions
  getData();
  calibrateData();
  directionToGo();
  newMovement();
  buttonPressed();
}
```

For the controllers there were two slightly different programs, one on the white controller to control the white tank and the other on the black controller for its corresponding tank. The differences however were only in a couple lines which sent different commands. The code utilises the virtual wire library which makes sending commands over the 433MHz wireless transmitter and receiver much easier. In the second week of the

Alternate Code For Black Controller

```
switch (c){
  case 0: movement("0"); break;
  case 1: movement("1"); break;
  case 2: movement("2"); break;
  case 3: movement("3"); break;
  case 4: movement("4"); break;
}

void movement(int c){ // sends the command to the receiver using the virtual wire library
  Serial.println(c);
  char *msg2 = c; //send 1 to the receiver
  Serial.println(msg2);
  digitalWrite(led, true); // Flash a light to show transmitting
  vw_send((uint8_t *)msg2, strlen(msg2)); //send the byte to the receiver
  digitalWrite(led, false); // Wait until the whole message is gone
  Serial.print("Test : ");
  Serial.println(msg2);
}

void buttonPressed() { // sees if the button has been pressed and whether it already was pressed
  if (buttonMode == 0) {
    if (digitalRead(button)) {
      buttonMode = 1;
    }
  }
  else {
    if (digitalRead(button)) {
      buttonMode = 0;
    }
  }
}

void shootLaser() { // if button has been pressed it sends this to the receiver
  if (buttonMode == 1) {
    movement("s");
  }
}
```

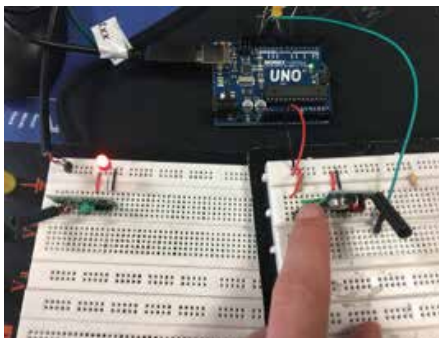


project I attempted to make my own wireless communication method using pulse width modulation, in that different duty cycles would signify different directions to go; however this was very unreliable, especially with the cheap transceiver modules which I was using and the noisy surrounding environment. This led to me using the virtual wire library due to the system actually working more reliably.

TANK:

RECEIVER:

The first part of the tank which I tackled was the wireless receiver. I started by making a simple circuit excluding the use of Arduino to send the information about whether a button had been pressed. After testing I determined that this system had a decent range, able to go across a room reliably. Once this was done it was simple to hook it up to Arduino.



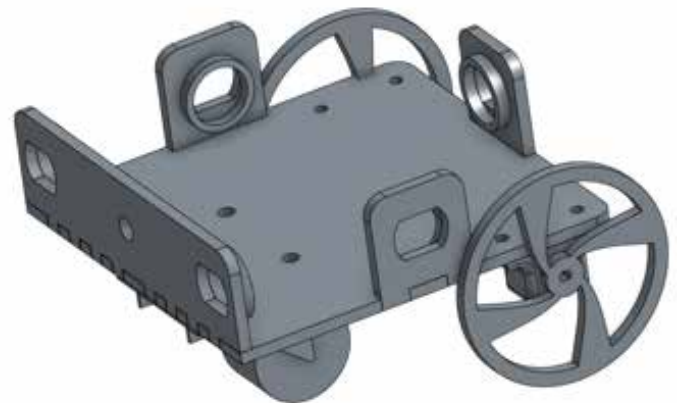
MOTOR MOUNT:

The irregular shape of the motors and lack of screw holes made it necessary to try 3D printing to get a workable solution. After measuring the various dimensions of the motors I made a model on OnShape and got it printing. The first model wasn't perfect and I learned many tricks to get a good print, such as avoiding large overhangs (the plastic sags) and having the most size sensitive parts in the same plane since the 3D printer that I was using (a CubePro [9]) was accurate at printing in the X and Y axis but less accurate in the Z axis. The speed of 3D printing allowed for many iterations of the print and therefore improvement. Near the end of the process it became apparent that the motors I was planning to use didn't have enough torque. For this reason I decided to get some motors with a 50:1 gearbox fitted. After readjusting the module and printing it out the resulting system worked much better.



CHASSIS/BODY:

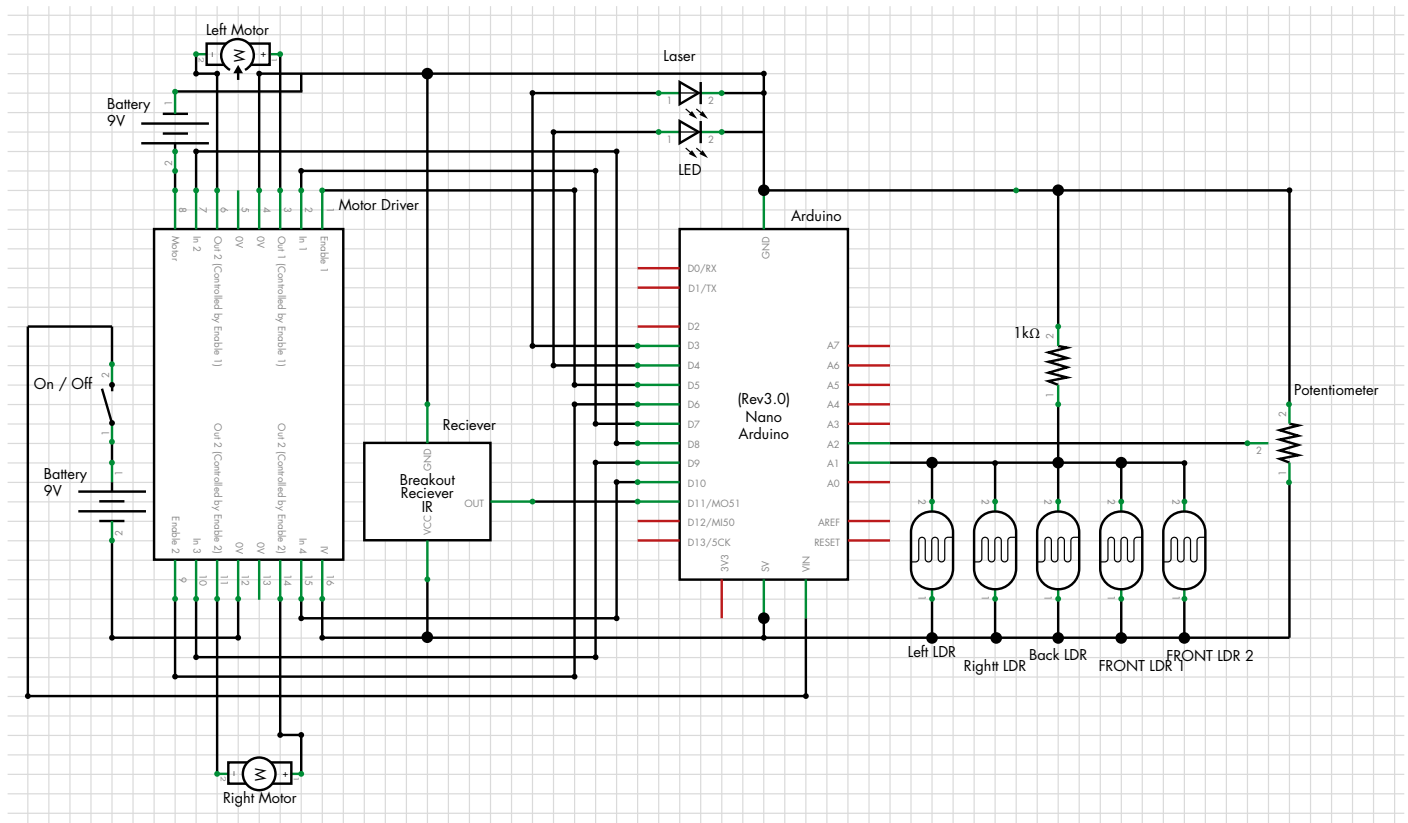
I envisaged that the main body of the tank would be a geometrically simple design and therefore that it would be suitable to use laser cutting technology to fabricate it. I once again used OnShape to completely design the project and then laser cut the final product onto 3mm and 5mm plastic. This was then glued together along the toothed joints resulting in a sturdy base for the project. The main change to the design on the project was the move from front wheel drive to rear wheel. This was because the caster wheel I was using was influencing the direction of the tank based on which direction it had been traveling previously. Elastic bands were fitted to the wheels to provide more traction, preventing the wheels spinning.



MOTOR CONTROL:

In order to power the motors without drawing all of the current from the Arduino I planned to use the L293D motor driver IC. This allows for easy speed control of the motors through the use of pulse width modulation (PWM) with the use of the PWM pins of the Arduino and the analogWrite(a, b) function where a is the enable pin of the motor driver and b is a number between 0 and 255 (0 off completely and 255 on completely) I used a potentiometer to control this number and therefore allow the speed of the tank to be adjusted.





ELECTRONICS:

After breadboarding the circuit below I moved it onto Veroboard; this was particularly important because the wires kept coming out of the breadboarding while the tank was driving, breaking it. This circuit was more complicated than the controller due to the secondary motor controller integrated circuit and multiple inputs and outputs. Once completed the system worked well and a potentiometer added afterwards to the circuit allowed for the motor speed to be adjusted, important since the speed of the motors increased when new batteries were added, leading to hard to control speeds. The second battery was added (the one top left in the schematic) to prevent an error I was encountering where the motors would draw too much current from the battery and therefore prevent the Arduino getting any, turning it off and breaking the system.


Originally I planned to have the 5 LDRs connected to 5 different analog pins. I decided against this however because it would lead to a slower running program (since more values for the Arduino to check). By putting the LDRs in parallel, this issue is negated since when the laser "hits the target" the resistance will drop from $M\Omega$ to $K\Omega$ leading to a large increase in voltage across the LDR which is measured by the Arduino. This is a simple potential divider [10].

PROGRAM:

The main loop of the code has two parts:

The first is to receive the commands from the controller. When it receives a message from the controller it checks what the instruction is. Depending on the instruction it then sends a message to the motor controller integrated circuit and turns the motors on, the speed of which is determined by the potentiometer. If the message from the controller is to turn on the laser then it turns the laser on for 0.2 seconds. This is achieved using the `millis()` function so that no delay is put into the main body of the code which would slow down the program significantly.

The second part of the main loop is to detect whether the tank has been "shot". When the Arduino detects an increase in voltage across the LDR it turns off the motors and turns on the LED which signifies that the tank has been "hit".



```

#include <VirtualWire.h>

const int ldr = A1; // pin LDR is connected to
const int pot = A2; // pin light potentiometer is connected to
const int laser = 3; // laser pin
const int deadLed = 4; // pin for dead led
const int enable1 = 5; // motor integrated circuit pins
const int enable2 = 6;
const int in1 = 7;
const int in2 = 8;
const int in3 = 9;
const int in4 = 10;
const int Rx = 11; // reciever module pin
const int led = 13; // on board led pin
const int motorPot = A3; // potentiometer to set speed of motors

int motorSpeed; // variable to hold speed of motor
int timeSinceRecieved; // variable to check connectivity
int timeOn; // variable for laser timings

void setup() {
  Serial.begin(9600); // Debugging only
  Serial.println("initiated");

  vw_setup(2000); // Bits per sec
  vw_set_rx_pin(Rx); // Rx Data pin to Digital Pin 2
  vw_rx_start(); // Start the receiver PLL running
  pinMode(laser, HIGH); //initialise IO
  pinMode(ldr, INPUT);
  pinMode(pot, INPUT);
  pinMode(motorPot, INPUT);
  pinMode(deadLed, OUTPUT);
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);
  pinMode(in3, OUTPUT);
  pinMode(in4, OUTPUT);
  pinMode(enable1, OUTPUT);
  pinMode(enable2, OUTPUT);
  digitalWrite(led, HIGH);
}

void loop() { // main loop that runs over and over
  recieve(); // gets commands from reciever module
  if (isDead()) { // checks whether the LDRs are lit up
    digitalWrite(deadLed, HIGH); // if so led is turned on
    nowhere(); // stops moving
    delay(5000);
    digitalWrite(deadLed, LOW);
  }
  if (timeSinceRecieved + 2000 < millis()) { // if no command is recieved for 2
    timeSinceRecieved = millis(); // seconds it assumes the link is lost
    Serial.println("ERROR COMMUNICATION LOST");
  }
}

bool isDead() { // checks whether the LDR resistance is greater than the potentiometers
  int ldrValue = analogRead(ldr);
  int potValue = analogRead(pot);
  if (ldrValue > potValue) {
    return 1;
  }
  else {return 0;}
}

void laserOn() { // turns on laser if for 1/5 of a second
  if (millis() < timeOn + 200) {
    digitalWrite(laser, HIGH);
  }
  else {digitalWrite(laser, LOW);}
}

void recieve() { // virtual wire library to recieve messages sent by controller and decode them
  uint8_t buf[VW_MAX_MESSAGE_LEN];
  uint8_t buflen = VW_MAX_MESSAGE_LEN;
  if (vw_get_message(buf, &buflen)) { // Non-blocking
    int i; // Flash a light to show received good message
    if (vw_get_message(buf, &buflen)) { // Non-blocking
      int i; // Flash a light to show received good message
      // Message with a good checksum received, dump it.
      Serial.print("Tank go : ");
      timeSinceRecieved = millis();
      for (i = 0; i < buflen; i++) {
        if (buf[i] == 50) {Serial.print("backward at speed of "); forward();} //if message matches
        else if (buf[i] == 49) {Serial.print("forward at speed of "); backward();} //command is made
        else if (buf[i] == 51) {Serial.print("left at speed of "); left();}
        else if (buf[i] == 52) {Serial.print("right at speed of "); right();}
        else if (buf[i] == 48) {Serial.print("No Where"); nowhere();}
        else if (buf[i] == 53) {Serial.print("LASER"); timeOn = millis();} // resets laser timer
      }
      Serial.println("");
      laserOn();
    }
  }

  void backward() { // sets the motors to go backward at a speed set by a potentiometer
    Serial.println(255-analogRead(motorPot)/4);
    motorSpeed = 255-analogRead(motorPot)/4;
    analogWrite(enable1, motorSpeed);
    analogWrite(enable2, motorSpeed);
    digitalWrite(in1, LOW);
    digitalWrite(in2, HIGH);
    digitalWrite(in3, LOW);
    digitalWrite(in4, HIGH);
  }

  void forward() {
    Serial.println(255-analogRead(motorPot)/4);
    motorSpeed = 255-analogRead(motorPot)/4;
    analogWrite(enable1, motorSpeed);
    analogWrite(enable2, motorSpeed);
    digitalWrite(in1, HIGH);
    digitalWrite(in2, LOW);
    digitalWrite(in3, HIGH);
    digitalWrite(in4, LOW);
  }

  void left() {
    Serial.println(255-analogRead(motorPot)/4);
    motorSpeed = 255-analogRead(motorPot)/4;
    analogWrite(enable1, motorSpeed);
    analogWrite(enable2, motorSpeed);
    digitalWrite(in1, LOW);
    digitalWrite(in2, LOW);
    digitalWrite(in3, LOW);
    digitalWrite(in4, HIGH);
  }

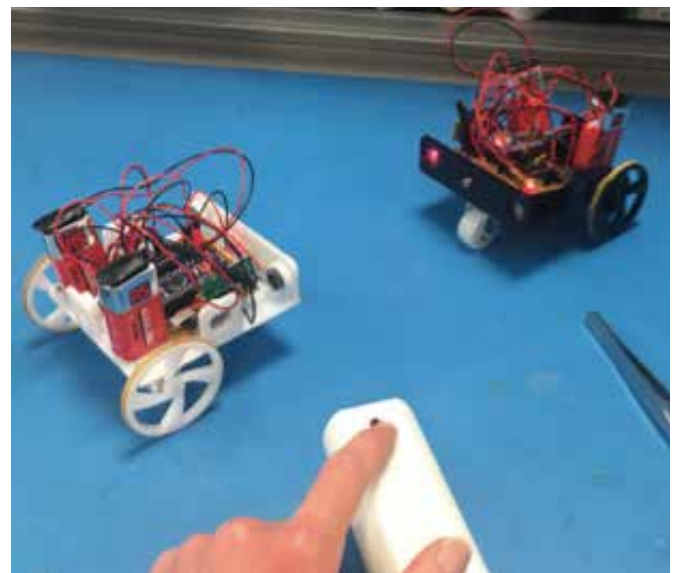
  void right() {
    Serial.println(255-analogRead(motorPot)/4);
    motorSpeed = 255-analogRead(motorPot)/4;
    analogWrite(enable1, motorSpeed);
    analogWrite(enable2, motorSpeed);
    digitalWrite(in1, LOW);
    digitalWrite(in2, HIGH);
    digitalWrite(in3, LOW);
    digitalWrite(in4, LOW);
  }

  void nowhere() {
    analogWrite(enable1, motorSpeed);
    analogWrite(enable2, motorSpeed);
    digitalWrite(in1, LOW);
    digitalWrite(in2, LOW);
    digitalWrite(in3, LOW);
    digitalWrite(in4, LOW);
  }
}

```

FINAL PRODUCT:

In the end I made 2 tanks with controllers; this number could easily be increased in the future to allow for more players. I did not have time to make a maze or course for it to be played in, although this could easily be as simple as a few cardboard boxes. The tanks can both be controlled over the 433MHz spectrum at the same time although if a command is given at the same time only one of the tanks will get the message. This is not ideal but not a game breaking limitation. The tanks are easy to control as long as you have the speed turned down and the laser and LDR system worked in all light levels I encountered. I expect games to last up to a few minutes depending on the skill level of the players. The total cost was about £30 per tank although if this were to be produced as a product that could be brought way down through bulk ordering and using a different, less easily prototyped microcontroller.



DISCUSSION:

LIMITATIONS:

There are several limitations to the product which I did not have enough time to address. Primarily these were the fact that if the lasers are not completely parallel to the floor then it makes it impossible to shoot the other tank since the LDRs are at a certain height. To combat this I had the lasers held in place with masking tape so that the height could easily be adjusted and changed in case the height changes while in storage. This is not ideal however and I would have preferred it if I could have got the laser fixed in place and parallel.

The second limitation is the batteries. Due to not having enough time between encountering the battery issue and the project deadline, no batteries were ordered. The batteries we were using were built brought 9V batteries with very little current output, I believe AA batteries would have worked better or alternatively a remote control car battery easily found online.

The final limitation was the wireless communication between the controller and tank. Since both controllers communicated over the same frequency they had some issues with interference. To fix this at the time I lowered the rate at which information was sent between the controller and tank by only sending a message when the direction changes and every second after that. This greatly increased the ability for both tanks to be played with at the same time; however it made individual control slightly worse.

FUTURE DEVELOPMENT:

I believe the system could be improved by addressing the three limitations mentioned above. Primarily this would involve having lasers fixed in their proper position. Furthermore fixing the battery issues and changing the frequency over which each tank communicates would help. If the system were to be mass produced its cost of £30 per unit could definitely be brought down considerably. Since it is an educational tool to help get prospective students interested in electronic engineering the product could easily be sold as a kit whereby all of the pieces have been produced but the student has to assemble, solder and code the product. I believe this would be a great avenue to go down since it would allow for expandability for students interested in the product and also promote the university, fulfilling its primary purpose as an educational institute.

CONCLUSION:

I learned a great deal while undertaking this four week placement. The skills I learned will be invaluable to me in the future and I hope that the product I produced will be useful to Dr Radu Sporea at the University of Surrey at future open days. The frustration I underwent due to hardware issues which I thought I had already checked were frustrating at the time but worth the effort to mitigate when it came to the final product which works well. In this way I have learned perseverance while also recognising the value of a fresh pair of eyes to look over the situation. To me this is vital in engineering due to the often team nature of large scale projects.

RECOGNITION AND THANKS:

I would like to thank primarily the University of Surrey, in particular Dr Radu Sporea for supervising the project and working with me over the four weeks. I would also like to thank Eva, a second year electronic engineering student who was invaluable offering expertise and answering questions. Finally I would like to thank SATRO who helped organise the placement and worked behind the scenes to make the project work.

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Give the Greeks a rocket, could they have reached the moon?

Hugo Burgess

The Ancient Greeks' earliest manuscripts are based largely upon myths in which the gods look down from Olympus, at times benevolently, although sometimes with capricious cruelty. It is no surprise therefore that the Greeks had a fascination with the heavens and the mysteries of the unknown. A creative and inquisitive people, their philosophers and scientists tried to explain the nature of the world around them. Debates raged between whether the Earth was flat or spherical, whether or not the Sun and Moon were divine, or whether the Earth orbited the Sun. However, if the Ancient Greeks¹ were to be presented with a rocket for their journey to the Moon, they would have needed not only the scientific and mathematical knowledge but also the desire to use it.

The Ancient Greeks did have primitive rockets of their own: around 400 BC, a Greek named Archytas built a rocket-powered pigeon. Suspended on wires, the pigeon moved along the ceiling by using steam propulsion, in exactly the same way a rocket today uses fuel. This utilises the physical principle that '*for every action, there is an equal and opposite reaction*'; Archytas obviously understood this concept, even though the actual law was only fully established by Sir Isaac Newton in *Philosophiæ Naturalis Principia Mathematica* in the 17th century. In the 1st century CE, Hero of Alexandria tackled the same problem with an invention of his own. His *aeolipile* also used steam to propel it as it rotated on its axis. Using a fire to heat water, he produced steam that was fed into a metal sphere; the steam was expelled from one of two ports, and this provided the thrust required to spin the device. Unfortunately, the Greeks did not have access to more sophisticated fuels; although the Chinese were producing a primitive form of gunpowder in 142 CE² and had even started developing gunpowder-powered arrows, the Greeks did not make such advances. Although oil had been discovered at that point, it does not seem to have been used as a fuel, but rather as an adhesive or as waterproofing for boats and buildings. Herodotus describes oil pits in a town called Ardericca:

Asphalt and salt and oil are drawn from it in the following way: a windlass is used in the drawing, with half a skin tied to it in place of a bucket; this is dipped into the well and then poured into a tank; then what is drawn is poured into another tank and goes three ways: the asphalt and the salt congeal immediately; the oil, which the Persians call rhadinace, is dark and evil-smelling. Herodotus 6.119

But although the Greeks understood their inability to breathe in hostile environments, such as under water, their underwater excursions only consisted of free diving for pearls or wartime missions; during the Pylos campaign of the Peloponnesian war, they provided food for the stranded soldiers:

...divers swam in by way of the harbour, dragging behind them in skins by a cord poppy-seed mixed with honey and pounded linseed... Thucydides 4.26

The Ancient Greeks had not even developed the sophistication of diving bells, let alone understood the concept of operating on the airless Moon.

The first space missions utilised maths that is relatively easy to comprehend: prior to the introduction of mainframe computers, calculations were performed by teams of human 'computers'; the Greeks were famous for pushing mathematical boundaries, would they have had the maths and knowledge required to reach the Moon?

Algebra is an essential component of the calculations necessary for space flight. Diophantus of Alexandria ushered in a new age with his introduction of algebra. Whilst his algebraic notation was simplistic (much of his notation used words instead of symbols and numbers – "*a sixfold number increased by twelve, which is divided by the difference by which the square of the number exceeds three*" Diophantus *Arithmetica*), it was revolutionary for the time, and it allowed him to refer to an unknown value. Much of modern maths has been based upon Diophantus' crucial work. In addition, he carried out important work on fractions, as he understood that they are numbers too – working upon quadratic equations, he accepted any rational solution, but did not require the answer to be a whole number. But perhaps his most important work was his *παρισότης* (approximate equality) for tangents to lines. Thus, Diophantus could calculate, to some degree of accuracy, the tangent of a line, a vital piece of information to understanding the trajectory of a rocket.

A core element of plotting the path of a space shuttle is calculus. Whilst a full understanding is not realised until much later, Eudoxus of Cnidus was already using primitive integration to calculate areas and volumes of different shapes. This 'method of exhaustion' foreshadowed the concept of the *limit* in today's mathematics. Euclid used this method to prove six of his propositions in *Elements 12*, concerning areas and volumes. Democritus proposed finding the area of an object by dividing it into an infinite number of cross-sections and then calculating from this base; he helped establish the concept of *infinitesimals* (things so small there is no way to measure them). Archimedes was a fan of this method, and used it to calculate, amongst other things, the area of a circle in his work *The Method of Treating Mechanical Problems*.

Another integral concept in spaceflight is *analytic geometry*, based on coordinates. The Greek mathematician Menaechmus has been credited

1. By using the term 'Greeks' (a separate group of city states that shared a common language, the same gods and a love of intellectual prowess), I usually mean any Greek-speaking people, from the Archaic to Hellenistic ages, who aided the collective search for knowledge that makes them such a fascinating civilisation.
2. The Kinship of the Three, Wei Boyang.



with introducing this, *The Age of Plato and Aristotle*, Carl Boyer. Apollonius of Perga also developed a method approaching analytic geometry in his work *Conics* using diameters, equations and tangents to explain curves; if he had realised that it was the equations describing the curves and not vice versa, he would have created the field himself around 1800 years before it was eventually established.

Another notable milestone in the journey to the Moon was the important discoveries of Aristotle and Eratosthenes. In Aristotle's work *De Caelo* he proposed that the Earth must be round based on the shape of the Moon during eclipses and how the stars' positions differ above Egypt and Cyprus "the form of this line will be caused by the form of the earth's surface, which is therefore spherical." (Aristotle *De Caelo* II.14). Eratosthenes added to this by accurately calculating the circumference of the Earth using the distance and direction between Alexandria and Syene and assuming the Earth was a sphere and that light rays are parallel to each other.³ With these facts established, Eratosthenes was able to calculate the circumference of the Earth to within an error of 10–15% of today's measurements. He also calculated the distance to the Sun as "σταδίων μυριάδας τετρακοσίας καὶ ὀκτωκισμυρίας" (of stadia myriads, four hundred and eighty thousand), which is remarkably close to today's measurement, worked out that there were 365 days in a year (and even that there would be an extra day every four years) and developed the *Sieve of Eratosthenes* used for discovering prime numbers.

Much of the information referred to by the Greeks would have originally been developed in Mesopotamia and Zoroastrian Persia. The conquest of Persia by Alexander the Great is a particularly significant milestone as it gave the Greeks an opportunity to tap into Persia's wealth of knowledge. In fact, Alexander recognised the benefit that science and learning might bring. He even sponsored medicine, suggesting remedies to his sick friends.

Moreover, in my opinion Alexander's love of the art of healing was inculcated in him by Aristotle pre-eminently. For he was not only fond of the theory of medicine, but actually came to the aid of his friends when they were sick, and prescribed for them certain treatments and regimens, as one can gather from his letters. Plutarch Alexander 8.1.

A solar eclipse in 585 BC ended a war between the Lydians and the Medians, who took it as a sign of the gods' displeasure, and brokered a treaty, despite the eclipse being accurately predicted by Thales of Miletus. Whether he devised his own calculation, or used the Egyptians' proto-Euclidian geometry, is unknown, because his method does not survive as proof.

...another combat took place in the sixth year, in the course of which, just as the battle was growing warm, day was on a sudden changed into night. This event had been foretold by Thales, the Milesian, who forewarned the Ionians of it, fixing for it the very year in which it actually took place. The Medes and Lydians, when they observed the change, ceased fighting, and were alike anxious to have terms of peace agreed on. Herodotus 1.74

The Antikythera machine, a form of early analogue computer from around 87 BC, predicted eclipses and the positions of the stars. Discovered on a ship that had sunk near the island of Antikythera, the device was possibly made by Archimedes, given that the mechanism's calendar was similar to the one used in Syracuse.

However able the Greeks might have been, there is also the problem of whether they would want to reach the Moon. The original myths about the gods would have discouraged many Greeks from challenging them by warning them of their hubris: the myth of Helios and Phaethon describes the Sun's passage across the sky, pulled by a chariot driven by Helios. One day, Helios succumbs to his son's pleading and allows him to drive. In his arrogance, Phaethon flies too close to the Earth and burns huge swathes into deserts and then, horrified, rapidly ascends, creating icy glaciers. Zeus, furious at the mayhem caused, flings a thunderbolt at the chariot and knocks Phaethon overboard to his death. This cautionary tale would have discouraged many from provoking Zeus' anger. Similarly, when Actaeon once spied Artemis, the goddess of the Moon, bathing naked in a pool, she was so furious that she turned him into a stag who was then torn apart by his own hunting dogs. Pragmatically, the Greeks also understood that the Sun held considerable power, despite its immense distance.

I decided that I must be careful not to suffer the misfortune which happens to people who look at the sun and watch it during an eclipse. For some of them ruin their eyes unless they look at its image in water **Plato *Phaedo* 99d**

But not all the Greeks believed in the gods: Socrates was famously put on trial, partly because of impiety towards the city's gods. Socrates did not so much reject gods as reference his own personal spirit (daimon) to help him reach decisions. Athens disliked the fact that he followed gods apart from their own. Meletus accused him of impiety:

Meletos himself ... sees through me so clearly and easily that he indicts me for impiety. **Plato *Euthyphro* 5c**

Protagoras was similarly sceptical of the gods: his famous quotation was considered dangerous and dismissive of the gods. Protagoras concluded that it was mankind who judged, and not the gods as was traditionally believed; he was banished and his works burnt by those who opposed him.

Man is the measure of all things, of things that are that they are, of things that are not that they are not. **Protagoras DK80b1**

Similarly, the scientist Anaxagoras was condemned to imprisonment for stating that the Moon did not emit its own light.⁴ In effect, Anaxagoras had claimed that the Moon was not divine but only reflected light from the Sun; it is interesting to note that he was prosecuted based on a law allowing impeachment of anyone who did not follow religious beliefs and who came up with theories of celestial bodies. Anaxagoras also proposed the correct explanation for eclipses, stating that the Sun was the only object emitting light as it was a red-hot stone. We can infer from this that he understood that the Moon was an object that passed between the Sun and Earth and blocked its light from reaching Earth.

3. "How did Eratosthenes measure the circumference of the Earth?" <https://todaslas cosas de anthonny.com/2012/07/03/eratosthenes-earth-circumference/>

4. B. Russell, *History of Western Philosophy*



And Diopeithes brought in a bill providing for the public impeachment of such as did not believe in the gods, or who taught doctrines regarding the heavens, directing suspicion against Pericles by means of Anaxagoras.

Plutarch Pericles 32.1

By contrast, several heroes completed their own *katabasis*. Odysseus undertakes a voyage to Hades in *Odyssey* XI, and despite the ordeal, he values the advice he receives from Teiresias and Achilles; similarly, Orpheus attempts to rescue his wife from the Underworld by enchanting Hades and Persephone with his beautiful music. This demonstrates the Greeks' willingness to venture into alien environments.

Even non-heroic Greeks were adventurous. Alexander the Great led his army into India, defeating King Porus, despite Porus' use of elephants (**Arrian *Anabasis* V.18**). Although Alexander's adventurous spirit tempted him to conquer India, his army was reluctant, and so he withdrew. I believe that Alexander's drive to discover and conquer would have led him to explore the Moon given the opportunity.

My father will anticipate everything; and for me he will leave no great or brilliant achievement to be displayed to the world **Plutarch Alexander 5.4**

Post haec Indiam petit, ut Oceano ultimoque Oriente finiret imperium (After this, he headed to India, in order to make the outer Ocean and the ends of the East the bounds of his empire) **Justin 12.7.4**

The Greeks' thirst for knowledge was not always appreciated, however: Archimedes, summoned by a Roman general, was reluctant to leave the circles he was drawing in the sand. The Roman soldier sent to fetch him grew so impatient that he killed him for his insolence. Whether this story took place is uncertain, but the Latin quote attributed to him was:

Noli turbare circulos meos! **Valerius Maximus**

Plutarch certainly did not deny that the event took place, but he made it clear that there were other stories about his death too.

But what most of all afflicted Marcellus was the death of Archimedes. For it chanced that he was by himself, working out some problem with the aid of a diagram, and having fixed his thoughts and his eyes as well upon the matter of his study, he was not aware of the incursion of the Romans or of the capture of the city. Suddenly a soldier came upon him and ordered him to go with him to Marcellus. This Archimedes refused to do until he had worked out his problem and established his demonstration, whereupon the soldier flew into a passion, drew his sword, and dispatched him. **Plutarch Marcellus 19.4**

From the very earliest days the Greeks were clearly interested in the Heavens; in the *Odyssey*, Homer describes the myth of the Aloadae who attempted to storm the Heavens by piling mountain upon mountain; no doubt the Greeks had a similar desire to visit the home of the gods:

Yea, and they threatened to raise the din of furious war against the immortals in Olympus. They were fain to pile Ossa on Olympus, and Pelion, with its waving forests, on Ossa, that so heaven might be scaled. And this they would have accomplished, if they had reached the measure of manhood; but the son of Zeus, whom fair-haired Leto bore, slew them both **Homer *Odyssey* XI.305**

It is no surprise therefore that Lucian of Samosata, in the 2nd century AD, wrote what has been described as one of the first science fiction novels. The plot revolves around Lucian, sailing out to explore the great Ocean, where his ship is whisked up to the Moon by a waterspout. He vividly describes the individual geographical areas of the Sun and Moon. Lucian is a satirical poet – perhaps his story was intended to challenge the veracity of contemporary myths by providing an equally implausible idea. The title (***True History***) is itself a further parody – his is the only truthful story as his is the only one acknowledging that it is lies. But I do not necessarily see that Lucian's satire hinders the ability of his story to be science fiction. Antonius Diogenes too recounts a journey to the Sun and Moon; it is interesting to note that they travel through the "territory of eternal night", which is a very good approximation for the darkness of space. Lucian deals with the topic of space exploration again in his other work *Icaromenippus* in which he details the journey necessary to reach Heaven:

Let me see, now. First stage, Earth to Moon, 350 miles. Second stage, up to the Sun, 500 leagues. Then the third, to the actual Heaven and Zeus's citadel, might be put at a day's journey for an eagle in light marching order.

Lucian *Icaromenippus* I

Lucian continues about philosophers: "*they have only to draw some circles, arrange a few triangles and squares, add certain complicated spheres, and lo, they have the cubic contents of Heaven.*" and very presciently "*they will tell you on oath the sun is a molten mass*".

It seems clear to me, therefore, that the Greeks would have attempted a Moon landing if they had had the opportunity; myths about the gods may have deterred some, but there was clearly a gradual shift in culture where certain philosophers began to question whether the gods existed at all. But it is also clear that the Ancient Greeks did not have sufficient technology or mathematical sophistication to make this journey possible. The modern world owes a great debt to the Greeks for creating and proposing new mathematical fields, but it is no surprise that it was left to later mathematicians to further develop the sophistication needed. However, I feel that their intellect and curiosity would have compelled them to accept the challenge.



Winner of the Fitzwilliam College Cambridge Annual Architectural Design Competition 2017

Nicholas Ratcliffe



PROJECT TITLE

The 'Fitz meeting hub' – an extended library space to accommodate group discussion and 1 to 1 interaction between students and fellows, positioned centrally within the existing buildings and gardens of Fitzwilliam College.

DESIGN NARRATIVE

My design objectives for the 'meeting hub' building were to...

- ☐ be a functional space to meet the needs of the students
- ☐ provide a productive workspace
- ☐ preserve the initial design aspirations for the college of Sir Denys Lasdun

This space should be used by fellows and students to meet, discuss and brainstorm ideas. Currently there is limited space in the college where students can meet and critique each other's work and so this hub would be an 'extended library space' for group work and discussion.

The main inspiration for my design came from Lasdun's original masterplan - his aspiration for a college design based around a spiral from the chapel, rather than the typical enclosed, grass courts of other Cambridge colleges.





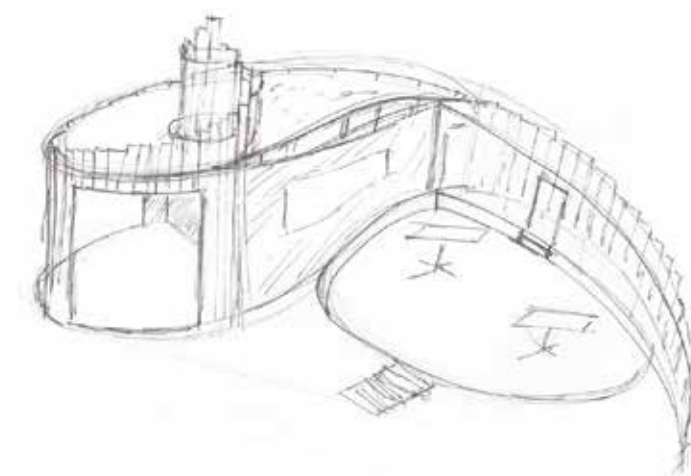
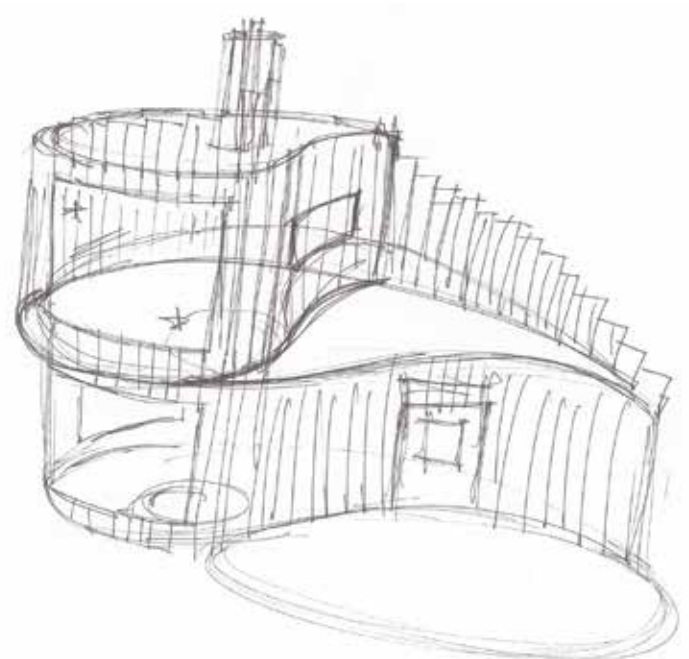
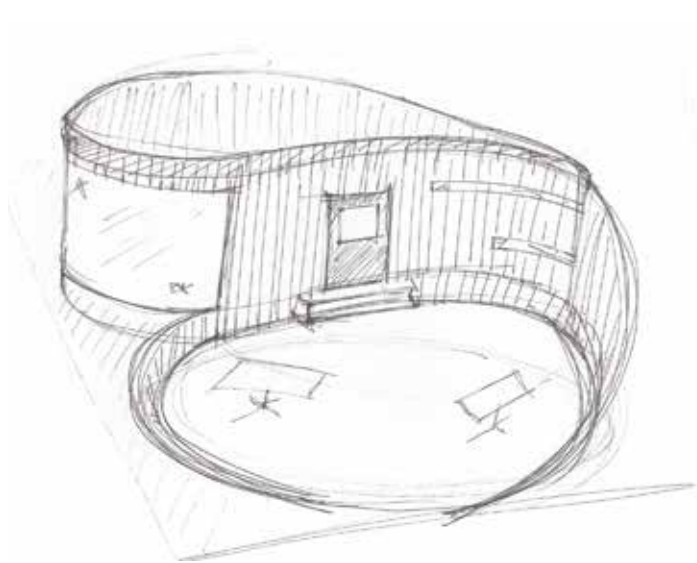
This inspired a solution based on the Fibonacci series and the golden ratio spiral; a series commonly associated with beauty in nature. The foundations of the design follow the spiral round the exterior walls of the building, right through the hedges into the patio area beside it. This spiral then continues throughout the college into the new learning spaces – through the Olisa Library, the lecture theatre in Wilson's court and Auditorium.

Inspiration for designing a productive and functional workspace came from beautiful modern garden art studios. Often, they are single storey, clad in wood, have glass façades and naturally provide a space for creative work.

The site selected is one of few untouched spaces in the college and was chosen due to its easy access and centrality to resources (including the Library).

Initially I zoned the site to evaluate best use of the limited space, followed by drawing initial concept designs to fit the brief. After working out the direction of sunlight, I took inspiration from Lasdun's masterplan and placed a golden ratio spiral over the site plan. This allowed me to make initial floor plans and develop the sketches before re-creating my concept in Google Sketch-Up.

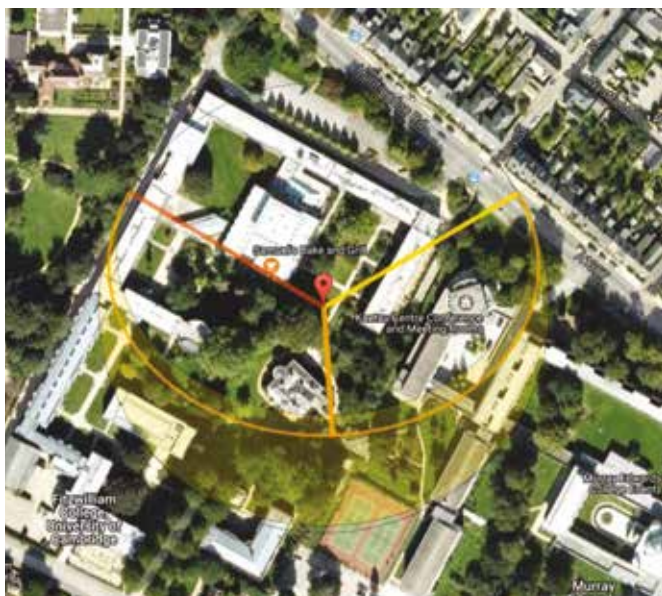
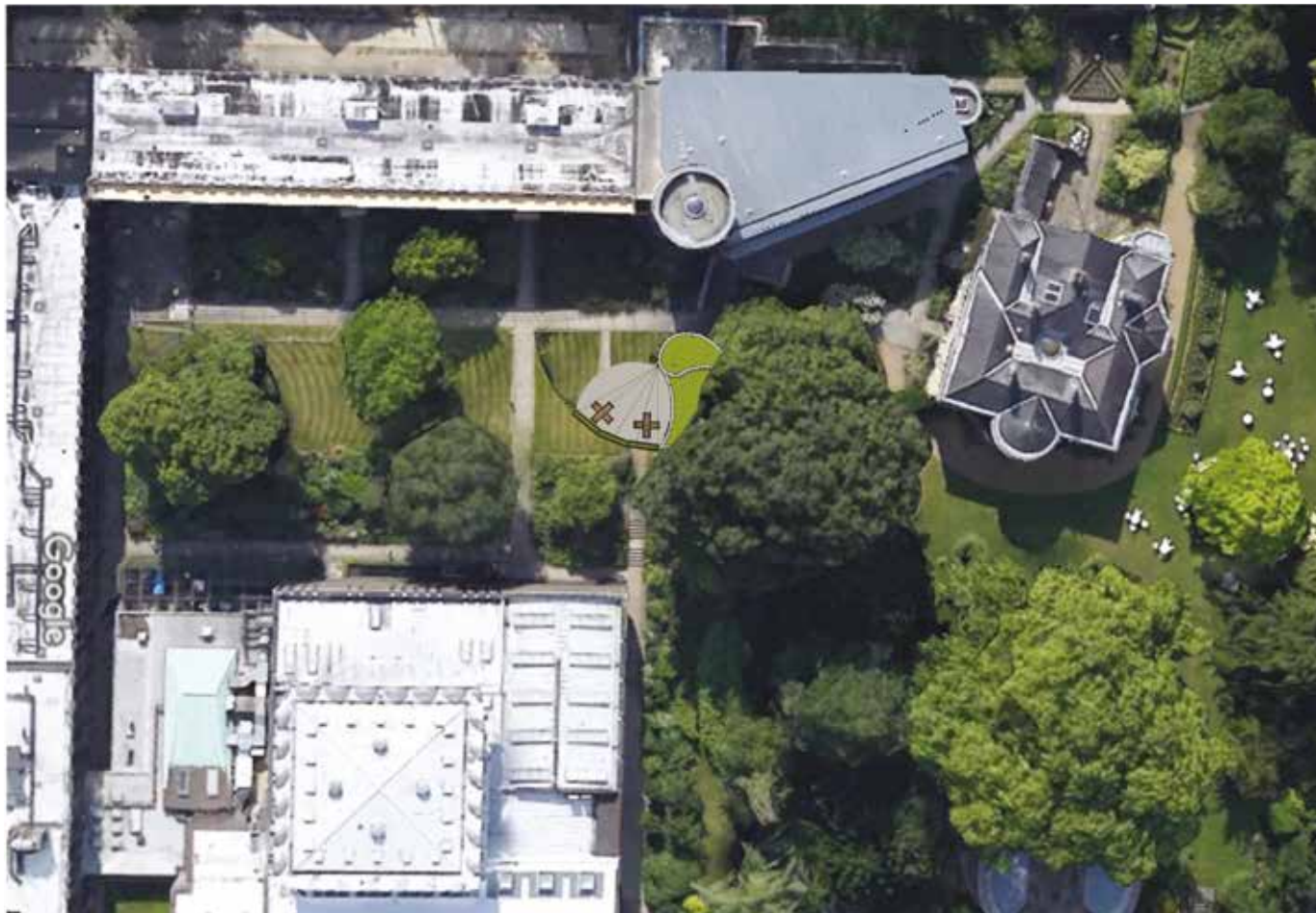
The building materials were chosen to retain aspects of Lasdun's original college buildings whilst also introducing more modern glass and wood façades. They included the use of dark red brick and concrete floors, found in many college buildings, with contrasting oak cladding like that on the library opposite. There is also use of weathered copper on the window frames and the brise soleil, a material which can be found on roofs of some of Lasdun's original buildings.



My design features an open plan layout, providing an open airy space in which groups can work, whilst also accommodating 1 to 1 meetings. The large glass windows allow in lots of light, making the relatively small room feel more spacious. This can be achieved because the coverage of the tree canopy provides protection from direct sunlight. Light can also enter the building through the sky lantern in the central glass pillar of the spiral staircase, which takes up minimal space. The secluded second story room provides more private space, surrounded by three large glass windows intended for students to write on, for example during small tutorial brainstorming sessions.



2D SITE PLAN



SITE SUN DIRECTION

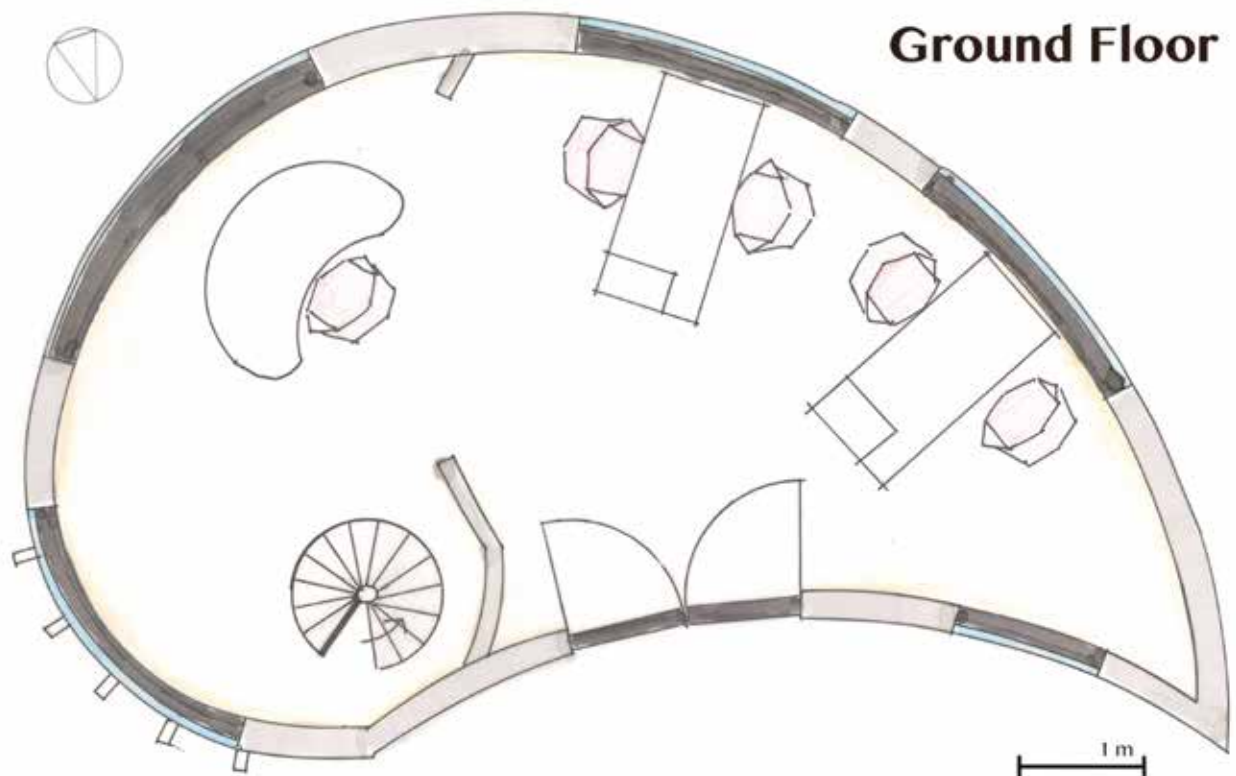
The orientation of the building was carefully chosen in relation to the direction of sunlight throughout the day. The large windows on the East side receive maximum sunlight during the morning as the sun rises above the library. During the morning, the patio also acts as a sun trap. However, during the afternoon, the south facing windows are protected from the summer sunlight by the tree canopy, which stops the building from overheating. This is also achieved by the insulation of the green roof.



3D SITE PLAN



GROUND FLOOR



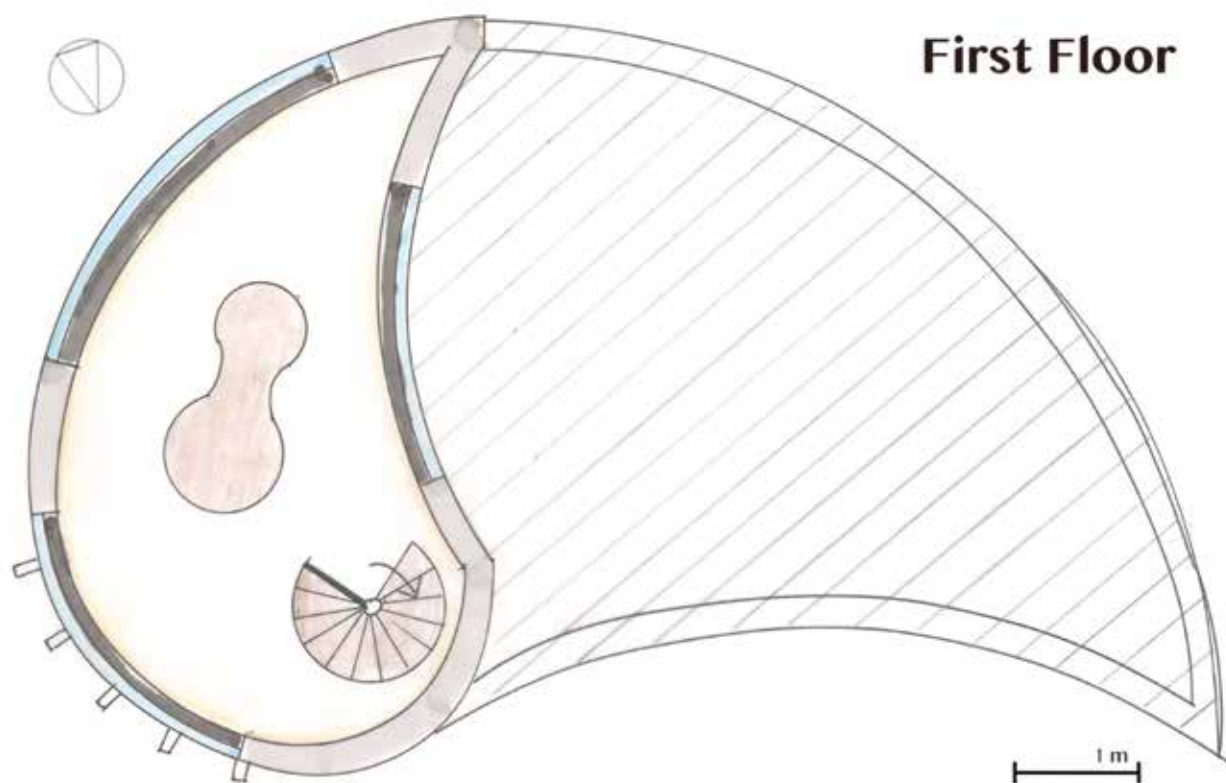
Project: Fitz meeting hub

Drawing: Ground Floor

30.5.17



FIRST FLOOR



Project: Fitz meeting hub

Drawing: First Floor

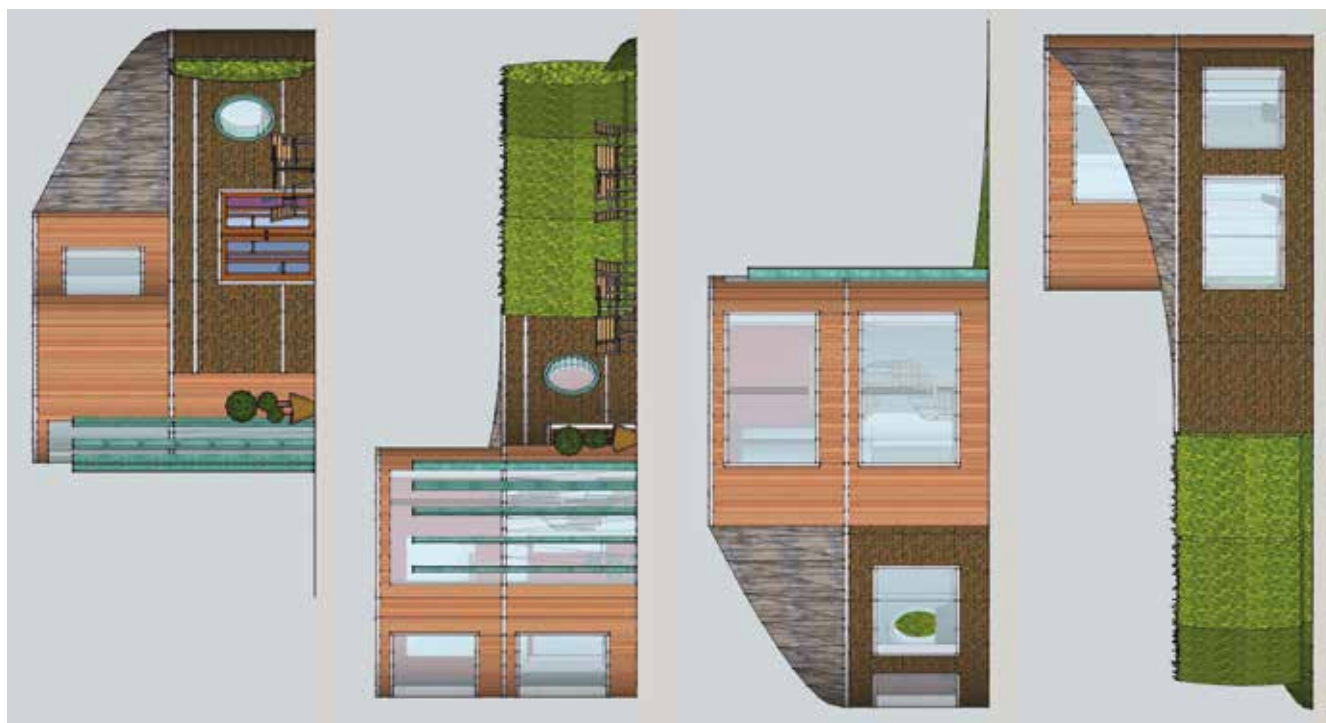
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NORTH

EAST

SOUTH

WEST

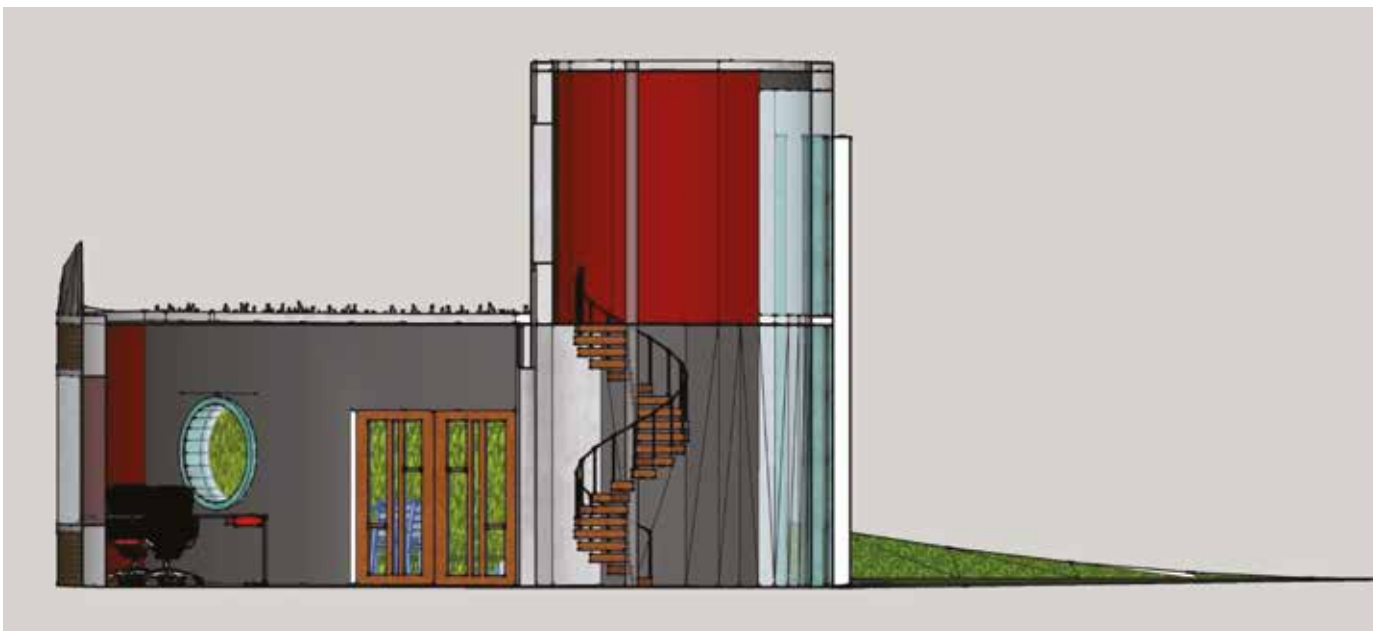




East Elevation



SOUTH BUILDING SECTION



VIEW FROM THE OLD PORTER'S LODGE



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Should specific performance be made a basic right of remedy for breach of contract?

Christopher Gooding

INTRODUCTION

In England, the non-pecuniary remedy of specific performance has been heavily restricted due to the adamant precedent in English case law, which insists that the retention of damages as the primary remedy for breach of contract is fit for purpose.¹ Presently, specific performance is limited by a strict set of principles, whose fulfilment is required before the court can grant specific performance as a remedy for a contractual breach. The main aim of a contract is to fulfil the expectations created by its creation, a concept known as the performance interest of the claimant.² On this basis, specific performance, as opposed to financial compensation (damages), should in theory be the purest form of fulfilling the performance interest:³ since, by ordering the exact performance originally contracted for, the performance interest is exactly fulfilled. Specific performance is not always possible, but in many cases it is not only possible but also desirable for the claimant. Hence why this paper argues that England should elevate specific performance to a basic right of remedy, alongside the right to damages, in order to provide optimal remedy for breach of contract.

In Part II this paper describes the application of specific performance and shows how specific performance works in practice.

Part III then challenges the current status quo, highlighting the often under-compensatory and ambiguous nature of damages, while showing that the tests of causation, remoteness and loss are much more efficiently applicable to specific performance. Moreover, a new one-stage test for the availability of specific performance (to be known as the 'in futuro' test), is proposed, in order to show how specific performance can work in tandem as a dual primary remedy. In fact, in certain cases, the very aim of damages, as set out by the courts, is revealed to be better fulfilled by specific performance.

This is followed by an assessment in Part IV of the preference between specific performance and damages. It is established that although damages are often preferable to specific performance, this is not always the case, and that the claimant is the best judge of the ideal remedy. Hence why the claimant should be able to choose between damages and specific performance.

Part V assesses the mutual benefit of placing the claimant in a position of being able to choose the remedy. The availability of specific

performance as a primary remedy is shown to put greater responsibility on each of the contracting parties to fulfill their part of the contract, reducing the chance of breach of contract and meaning parties can enter into contracts with greater confidence in the completion of their performance interest.

The proposed dual remedy system of specific performance and damages is submitted in Part VI, which demonstrates that by elevating specific performance to a basic right, and thereby placing equity as a precedent, a fairer more efficient system of law will be formed. This is caveated by the assurance that the elevation of specific performance to a position of right is not a reversal of the current system of damages; damages should remain the most common form of remedy, however the free availability of specific performance will provide tangible benefits to both the courts and contracting parties.

Part VII provides the conclusion, and emphasizes that by employing the 'in futuro' test, the court will be able to put the choice of remedy at the claimant's discretion, leading to a fairer, more efficient legal solution to the breach of contract.

THE APPLICATION OF SPECIFIC PERFORMANCE

Before undertaking to show why specific performance should become a basic right of remedy, it is important to clarify in exact terms what exactly specific performance is. Drukker⁴ defines specific performance as:

"an equitable remedy. When the court orders specific performance, they are ordering one party to perform a contractual obligation."

The first thing to note is that specific performance is an equitable remedy. The idea of equity goes back several centuries to when English courts began denying plaintiffs legal remedies for what seemed to the common layperson perfectly acceptable grievances (e.g. tenant and landlord disputes). Such denials were on the basis that such grievances did not align with legal technicalities or precedents laid down by the common law. Consequently this led to the formation of an alternative set of courts known as the Chancery, which gave case by case remedies based on conscience and

1. *Lawteacher.net, Law dissertation topics, 2017*

2. *M. Chen Wishart, Contract Law, 2010, p.541*

3. *A. Schwartz, 'A case for Specific performance', Yale Law 1979, p.271*

4. *Drukker Solicitors Eldon Chambers, Portfolio_Specific-Performance, Drukker.co.uk, 2017*

5. *Farlex, Legal Dictionary, Equity, 2017*



common sense; these remedies came to be known as equitable.⁵ Over time equity came to be defined as being limited to cases within which pecuniary relief was inadequate, and it is this idea which informs the modern sense of the term. To describe a remedy as equitable is not to disenfranchise it from legal precedent and legislation (as may have been the case in the 13th and 14th centuries), but rather to demark the remedy as being non-pecuniary, or non-compensatory (financially speaking). An equitable remedy is therefore remedy by performance rather than by compensation, the quality of this performance being specified by the nature of the contractual obligation. To put it simply, specific performance is the fulfillment of the original contract.

The case of *Phillips v. Lamdin* [1949] gives an archetypal example of specific performance. The facts of the case were as follows:

The claimant agreed to purchase a house from the defendant which included a rare ornate door. The defendant delayed the sale of the house and removed the door prior to the completion of the sale. The claimant then sued for breach of contract and the court granted the claimant specific performance issuing an order for the defendant to return the door and complete the contract, thus fulfilling the exact performance interest of the claimant, the purchase of a house equipped with a rare ornate door.

THE STATUS QUO

Although, the case of *Phillips v. Lamdin* shows that specific performance is available as a remedy for the court to grant at its discretion, unfortunately for the claimant it is rarely used due to the overriding precedent that damages offer the best remedy for a contractual breach. The aim of damages is to “put the injured party into the position, as far as is possible, that they would have been in if the contract had been carried out”⁷, and if that is not possible then to put the injured party in a “position as if the contract had never been made”.⁸ Damages are meant to be restorative not punitive, an act of compensation meant to reimburse the claimant rather than punish the defendant.⁹ Through the centuries, the development of damages as a remedy has led to a highly effective tripartite legal test for whether a contractual breach carries legal liability; namely the tests of causation, remoteness, and mitigation of loss. Firstly, causation tests whether there is a direct chain of causation between the action of a breach and the loss of a claimant; remoteness refers to the foreseeability tests where it needs to be established that the loss of the claimant must have been reasonably foreseeable¹⁰ to the defendant; thirdly, mitigation of loss tests whether the claimant acted reasonably to try and mitigate the overall loss caused

by the defendant’s breach. This tripartite test, although competent, has been the cause of much legal controversy and House of Lords rulings, and the defence for a damages claim will usually involve showing that that one or more of these tests fails on the smallest of technicalities. The contentious nature of these technicalities inevitably results in unsavoury decisions. Take for example the case of *Victoria Laundry LTD v. Newman Industries* [1949], where the claimants were unable to sue for loss of profits from government contracts that would have been secured were it not for the failure to Newman Industries to complete the contract. The claim was rejected since it was deemed that the breach was too remote from the loss of profits.

The further test the court applies for the granting of specific performance is also polyatomic: damages must be an inadequate remedy; the judge must give their discretion¹¹; and specific performance cannot be applied to certain types of contracts (e.g. contracts for personal service and contracts that would require constant superintendence from the court)¹². Therefore in the current court system, a complex multi-faceted test (the damages test followed by the specific performance test) must be fulfilled for specific performance. This is not only inefficient but also unfair, since when taken as a unique basic right of remedy, specific performance becomes much easier to apply than damages. We have already seen that specific performance is primarily concerned with fulfilling the performance interest of the claimant, as such specific performance can only be pursued in cases where performance is ongoing or yet to be done. The idea of a chain of causation existing between breach and loss is therefore void since breach is loss¹³. So too the remoteness test is deemed void since the point of breach is also the point of loss. Lastly the idea of mitigation is replaced by the principle set by precedent that specific performance will only be granted if the claimant is also willing to perform, or has performed, his side of the bargain.¹⁴

Hence why a new test for the availability of specific performance is being proposed. This new test progresses from the idea seen in consideration, where consideration be regarded as executed, or executory, based on whether performance is ‘in futuro’.¹⁵ Quite clearly for a case in which performance, whether it be incompetent or inferior or inadequate, has taken place, specific performance is an impossible remedy. Consider the case of *Ruxley Electronics and Construction LTD v Forsyth* [1995]: The claimant contracted the defendant to construct a swimming pool at a cost of £70,000. The swimming pool was completed but not to the depth stipulated in the contract. According to my ‘in futuro’ test the claimant would not qualify for specific performance but would instead be forced to pursue damages. Thereby reaching the same decision that the House of Lords themselves reached, that the claimant was entitled to nominal damages.

6. Emily Finch & Stefan Fafinski, *Contract Law, Specific performance Key Case*, 2013, p.202

7. Emily Finch & Stefan Fafinski, *Contract Law, Damages Key Definition*, 2013, p.189

8. Samantha Cotton, *Remedies for breach of contract*, uk.practicallaw.thomsonreuters.com, 1999

9. Per Lord Atkinson in *Addis v. Gramophone Co. Ltd* [1909]

10. Per Asquith LJ in *Victoria Laundry v. Newman Industries* [1949]

11. The judge’s discretion is based on principles seen in precedent (e.g. misbehaviour of claimant, vagueness of contract etc.)

12. Michael Furmston, *Law of Contract*, 2012, p.800

13. If the loss for the promise is his exact performance interest, then by virtue of breaching the contract, the promisee has incurred loss

14. Emily Finch & Stefan Fafinski, *Contract Law, Remedies*, 2013, p.204

15. Michael Furmston, *Law of Contract*, 2012, p.102



However, in the case of *Brace v Calder* [1895] performance would be deemed as being 'in futuro' (yet to be performed or requiring continued performance). The case was as follows:

The claimant was offered employment for a period of two years, after five months the company was dissolved, cutting short the claimant's employment. A splinter company was formed at which the claimant was offered employment which he refused. The claimant subsequently sued for damages of earnings for the 19 months of his expected 24-month employment.

According to the 'in futuro' test the claimant qualifies for specific performance; a salaried 19 months performance of employment, which in this case the defendant has already offered him. If he instead chose the remedy of damages, as was the claim in the actual case, damages would be refused based on failure to mitigate for loss. If the facts had been changed, and the splinter company not offered him employment, in the current system the claimant would still only be able to sue for damages and then be refused them based on lack of mitigation of loss. However, were he able to sue on the basis of specific performance the court would order the splinter company to offer him employment, a fair and just outcome, as opposed to the under compensatory damages that would have granted him nothing. Such is the way in which specific performance can work in tandem with damages as a joint basic right of remedy to offer a fair solution to a breach of contract.

As stated at the start of this section: The aim of damages is to "put the injured party into the position, as far as is possible, that they would have been if the contract had been carried out". Specific performance fulfills this to the letter, whilst also offering a much simpler test than damages, showing why specific performance should not be a secondary remedy to damages.

CLAIMANT'S DISCRETION

It is important to immediately dismiss the notion that specific performance would somehow replace the role of damages. A case that failed the 'in futuro' test would automatically be argued on the basis of damages. Yet even in cases that pass the 'in futuro' test, damages may still be preferable to the claimant. Hence why it should be up to the claimant, not the court, to decide their ideal remedy. For example, in *Brace v Calder* [1895]¹⁶ the disenfranchised employer may not have sought specific performance on the basis that he no longer trusted the defendant to provide him with a steady employment.

The case of *Ryan v Mutual Tontine Westminster Chambers Association* further demonstrates the blurred lines between specific performance or damages acting as the ideal remedy. The facts of that case follow:

The lessor of a block of flats agreed to appoint a resident porter to perform duties for the tenants including cleaning, receipt of parcels, and delivery of letter. The porter appointed was a part time cook,

and vacated himself of the premise for several hours each day to act as a chef at a neighboring club. During his vacations, his duties were performed by various boy and char women not resident on the premises.¹⁷

The courts held that specific performance be an inappropriate remedy and that an action for damages be the only remedy. Yet it seems here that the claimants have been extremely hard done by, given their assumed performance interest. Assuming they wanted a resident porter, and made an agreement to have a resident porter, it only seems fair that they are given the option of having a resident porter. It is perfectly reasonable for them to desire a court order to the lessor to fulfill the specific performance of the contract. Conversely, the claimants would perhaps have preferred to take the pecuniary damages, and dispense with their desire for resident portership. If their performance interest in the contract was merely the completion of the duties of "cleaning, receipt of parcels... etc.", then damages would be adequate as the residency of the porter had no effect on the completion of these duties. Had their performance interest been the specific presence of a resident porter, then specific performance would best fulfill their performance interest, and vice versa. Depending on the claimant's performance interest, the ideal remedy is different, demonstrating why the best judge of the efficiency of the remedy is the claimant and not the courts.

Even in the current system, specific performance is sometimes forced upon a claimant by a court, even in a situation when it is undesirable to the claimant (e.g. remedy for sale of land contracts). It is not much noticed that purchasers of houses or land, for example, may sometimes prefer liquidated damage clauses instead of specific performance because sellers in possession during the specific performance action might cause damage that would be difficult to prove in court¹⁸. Furthermore, in the case of *Phillips v Lamdin* discussed in Part II, where the claimant was given specific performance for the breach of a sale of house equipped with unique ornate doors, the claimant may in fact have preferred to pursue damages if the value of damages exceeded the value he himself placed on the inclusion of unique ornate doors. Preference is context dependent¹⁹ and as such the claimant should have the discretion to pursue their ideal remedy.

MUTUAL BENEFIT

A central argument against giving the claimant a choice in the remedy is that the claimant is placed in an unfairly strong position. Such an argument ignores the fact that the claimant is the wronged party and therefore has every right to pursue justice. To put the claimant in a position of choice does not mean a punitive remedy that unfairly burdens the defendant, rather it means a more complete compensation that fully satisfies the wronged promisee²⁰. Moreover, the defendant himself can benefit from the claimant choosing a remedy different to what would be granted if the court were to

16. Analysed in Part III

17. Michael Furmston, *Law of Contract*, 2012 p.802

18. A. Schwartz, 'A case for Specific performance', *Yale Law* 1979, p.284

19. A. Schwartz, 'A case for Specific performance', *Yale Law* 1979, p.284

20. *Legal Dictionary*, duhaime.org : "Promisee, one to whom a promise has been made."



choose. For example, in the sale of unique goods, the promisor²¹ would better be able to breach the contract and pay damages, due to the possible fluctuation in price a unique good can command²². Similarly, the promisor of a non-unique good would be better off fulfilling his contract by specific performance, as he is likely not to get a better price for his good in the future. Both these preferences are contra to the current precedent in English courts, which orders specific performance for unique goods, and damages for non-unique goods. Hence why when giving the claimant discretion, even the defendant can benefit.

Moreover, the freer availability of specific performance heightens the responsibility of the promisor and makes them more likely to fulfil the contract. Since if a promisor were to breach, be successfully sued for an action of specific performance, and then breach again, the promisor would be at risk of contempt of court, an extremely serious crime that can entail serious fines and sometimes imprisonment. This in turn means that the promisee can go into a contract with much more confidence that the contract will be fulfilled and their performance interest satisfied. Contracts would be made stronger and more breach-proof by the existence of claimant discretion.

Figure 1

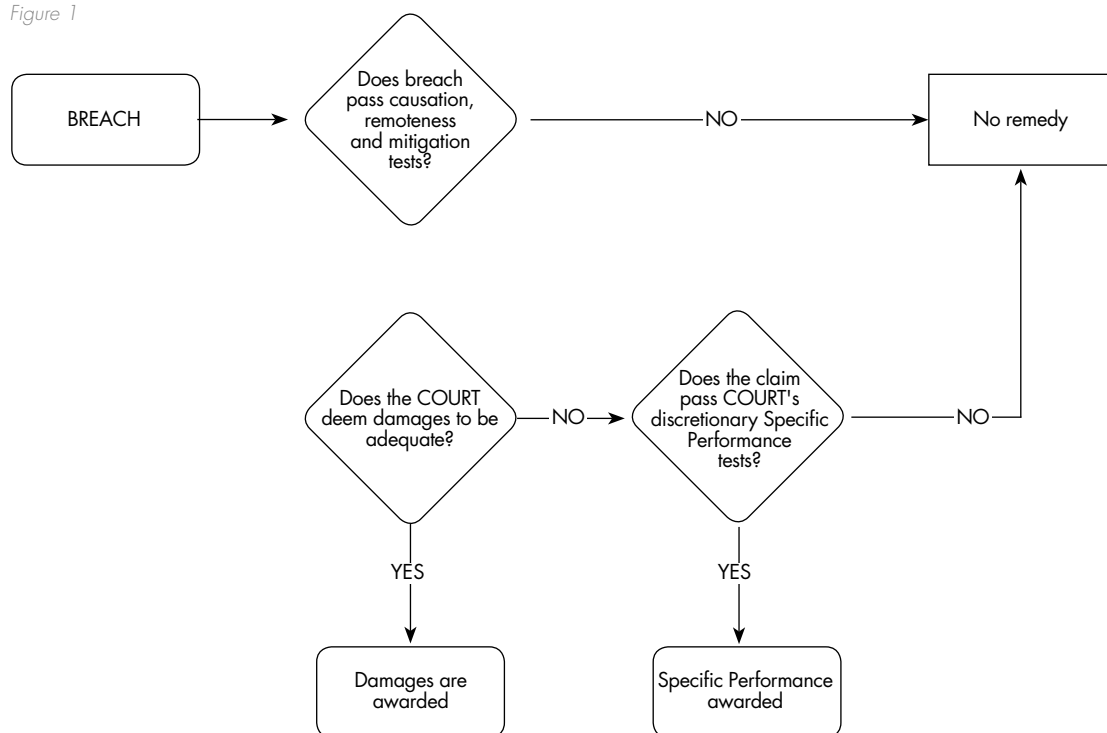
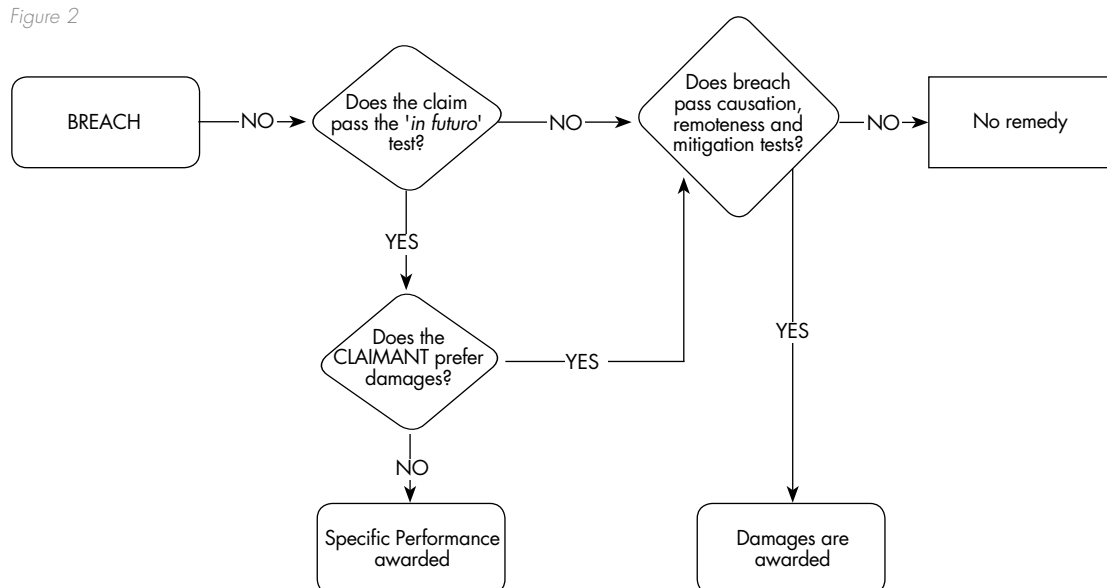


Figure 2



21. "Promisor, one who makes a promise, the person who has become obliged through a promise (usually expressed in a contract) towards another."

22. If a seller of a unique good, having agreed sale of that good, then realises that the actual value of the good may in future fluctuate so as to far exceed the current value of the good, then it could be most economic for him to breach on the contract, pay damages, and then sell the good in future for a much greater price.



DUAL-REMEDY

Figure 1 shows a flow chart representation of the current way of determining damages. Figure 2 shows the proposed dual remedy system of equitable and financial remedy. As can be seen, the dual remedy system is not a reversal of current precedent but rather a necessary development to both streamline and make fairer the remedy to breach of contract. Not only does a dual remedy system provide the claimant with their preferable remedy, but also makes obtaining remedy more likely, as shown by the diagram. In this new system, equity will now command a more principal place in remedy, a position that only seems right given the traditional definition of equity as fairness.

CONCLUSION

Having seen how damages can often be inadequate, how specific performance can often be preferable, and how the claimant is the best judge of ideal remedy, it only seems right that specific performance be made a basic right of remedy in a dual remedy system.

The 'in futuro' test offers a unique way to differentiate cases into those in which specific performance is possible, and those in which it is impossible, before giving the claimant the choice between damages or equity. Equity is worthy of its place in the remedy of breach of contract, and a dual remedy system is the fairest, most efficient legal solution to an issue that is vital to business and economy. In answer to the question: legal logic, economic considerations, and the pursuit of a freer fairer society demand that specific performance be made a basic right of remedy for breach of contract.

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Investigating bone mineral density in children and adolescents with cystic fibrosis, should we be doing less monitoring?

Ciaran O'Toole, supervised by Professor Andrew Bush of Imperial College London

BACKGROUND

Cystic fibrosis (CF) is an autosomal recessive disease caused by mutations in the cystic fibrosis transmembrane regulator (CFTR) gene. This means that the physical symptoms of CF will be manifested if two abnormal copies of the gene are present. The CFTR gene codes for the production of channels embedded in the cell surface membranes of epithelial cells that allow for the movement of chloride ions in and out of cells. Once there is an error in the coding of the gene, the number of functional channels present is decreased, and the movement of chloride ions is constricted. Chloride ions are crucial in maintaining a constant water concentration balance and so when this balance is disrupted, this leads to a build-up of dehydrated secretions (thick mucus) which is responsible for so many of the symptoms associated with CF.

When CF was first described, the major symptoms were from the respiratory, reproductive and digestive systems. Respiratory problems stem from the build-up of thick and sticky mucus in the lungs, which promotes bacterial infection. Reproductive and digestive system problems arise from the blockage of major ducts e.g. the sperm and pancreatic ducts. The pancreatic duct is where crucial digestive enzymes are transported to the intestines and the sperm duct takes sperm for sexual reproduction. When these ducts are blocked, digestive insufficiency and reproductive issues arise, which are characteristic

of CF. Currently there are 10,500 registered patients in the United Kingdom and due to advances in modern treatments, fewer than six children a year die of CF. Because of these increased survival rates associated with CF, there are now more adults than children and the more underlying complications associated with the disease are being appreciated, which extend further into adulthood.

One of these relatively novel CF complications is a reduced bone mineral density (BMD) and therefore a heightened risk for osteopenia and osteoporosis. The link between CF and bone disease was first described in 1979 by Mischler et al. who found that 44% of CF subjects had an abnormal BMD (>2 standard deviations below the control group mean). Bone disease is multifactorial and there are a number of risk factors such as the types of drugs taken in treatment for CF, malnutrition and lifestyle factors.

The national guidelines commissioned by the National Institute for Health and Care Excellence (NICE) for monitoring BMD in CF patients recommends dual energy X-ray absorptiometry (DEXA) bone density scans for those with CF at high risk for an abnormal BMD. On a regional level, the guidelines currently in place at the Royal Brompton Hospital (a leading specialist CF centre in London) dictate that the BMD for all CF patients is monitored from age 8 onwards in alternate years. If the bone density is found to be abnormal, the scans are repeated annually.

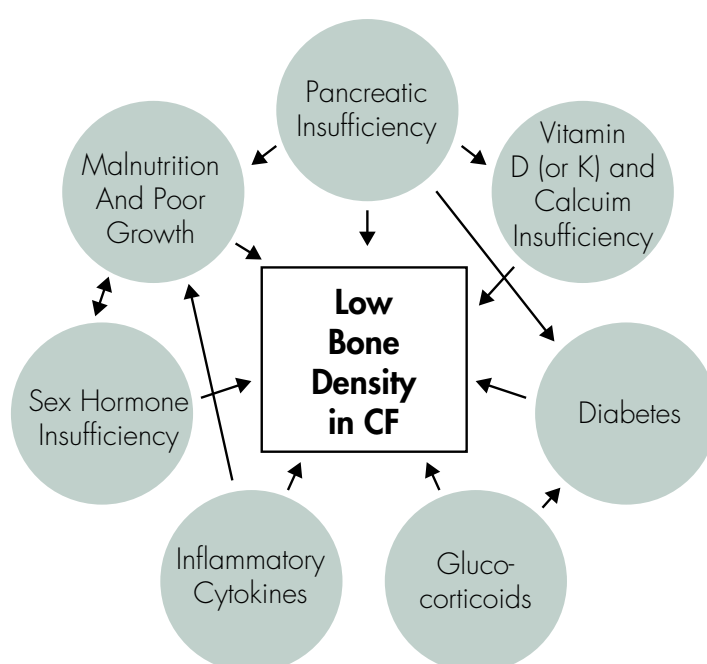


Figure 1 showing the contributing factors to a low BMD



AIMS

Since bone health in children has not been well documented in the CF literature, this study was undertaken to obtain a better understanding of bone disease to inform the practice for future patients. The main aims of the study were:

- 1) To explore the extent of low BMD in children with CF
- 2) To identify risk factors associated with decreased BMD
- 3) To establish the rate of decline in BMD to inform future practice
- 4) To audit the effectiveness and appropriateness of current guidelines

METHODOLOGY

Patients were selected from the UK CF Registry database born between 2000 and 2006 and currently receiving care at the Royal Brompton (RBH). 153 patients were assessed for eligibility, 96 patients were included in the study (59 female 37 male); 57 patients were excluded for either not meeting the inclusion criteria or not being a current patient receiving treatment at the RBH. Variables were collected from the RBH electronic patient records and DEXA databases, including:

- ☐ Gender
- ☐ Age
- ☐ Ethnicity
- ☐ Lung function
- ☐ Body mass index (BMI)
- ☐ Gene mutation classes
- ☐ Diabetes status
- ☐ Microbiology
- ☐ Vitamin D, ALP and calcium levels
- ☐ Medication use

RESULTS

In the full study, only eight out of the 96 patients had an abnormal bone density at the first scan (8%) and only 13 patients were found to have one throughout the full course of the study (14%). Figure 3 is a boxplot showing the progression of lumbar spine 2 (L2) BMD z-scores for the cohort. The general trend is that the median bone density decreases over the progressive scans. Using ANOVA statistical tests, this rate of decline was shown to be significant for L2 (shown) and L1–L4 ($P=0.008$). This is backed up by Table 1, which shows that the average decline of BMD over time is roughly about $-0.1 (\pm 0.3)$ z-scores per year. As shown in Table 2, as the bone health decreases over the progression of the scans, so does lung function (FEV1%). FEV1% is a measure of a patient's actual lung function as a percentage of their theoretical lung function for a person with the same age, ethnicity, height and weight. Lower than 80% is generally considered to be abnormal. Vitamin D levels fluctuate around the 70 level, which is way above what is considered to be a normal level (0–25 is considered to be insufficient, 25–50 is considered to be low, and 50–75 is perfectly normal for vitamin D). No patients in the entire study who displayed an abnormal bone density had an insufficient vitamin D level. Body mass index (BMI) z-scores show the relative standard deviations a patient's BMI ($\text{weight}/\text{height}^2$) is from their matched mean on a standard deviation bell curve. There is a reduction in BMI z-scores between the group with an abnormal BMD compared with the group without an abnormal BMD as shown in Tables 3 and 4. This leads to reinforce the fact that an abnormal BMI z-score is an indicator for having an abnormal bone density. A stepwise logistic regression test was done using L2 z-score as the dependent variable. The factors found to be associated with a lower z-score were FEV1, BMI z-score, Aspergillus status, and gender (females are placed at a higher risk). The factors not found to be associated were Vitamin D, age, Pseudomonas status, and CF-related diabetes.

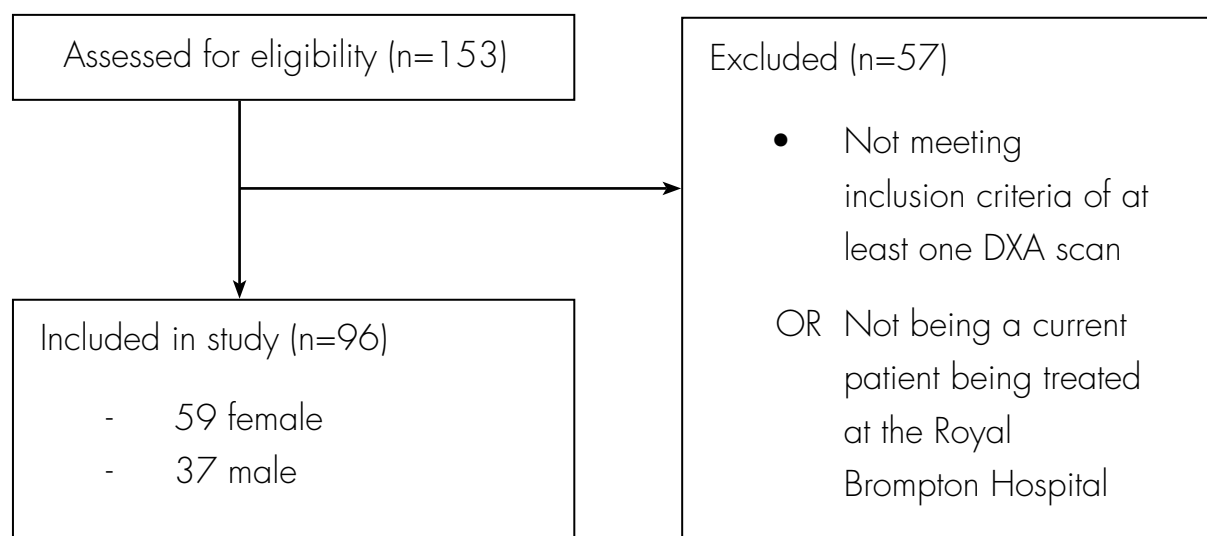


Figure 2 showing the selection process for candidates for inclusion into the study



CONCLUSIONS

Fewer than 15% of adolescents were ever found to have an abnormal bone density. Low lung function and BMI z-scores were the greatest indicators for being at risk for osteopenia for the cohort. There was no evidence to support the theory that vitamin D was a contributor to paediatric bone disease. With a rate of decline of -0.1 z-scores per year then the frequency of screening could be decreased in low-risk patients to around twice through childhood and adolescence.

Limitations of the study – Patients at higher risk for osteoporosis will have a higher number of scans than other patients, which could skew results. To combat this, in stages of analysis, only the primary scan result was used. The RBH guidelines that dictate that scans are commenced biannually from age 8 was only introduced in 2011. Because of this, patients born between 2000 and 2003 do not have an initial scan date that is at age 8, which has been accounted for in analysis. The DEXA scan is not a 100% reliable representation of bone mineral density. It scans a cross section of the bone for the mineral content; however, it is a two-dimensional scanning tool for a three-dimensional reality. In this way, the bone mineral density measured by the machine will be larger for a bone that has larger dimensions when compared with a bone with the same mineral density but smaller dimensions. In this way, patients have been matched for weight and height to ensure that results are not significantly skewed.

WERE THE AUDIT STANDARDS CARRIED OUT?

RBH protocol says that all patients with an abnormal DEXA result (z-score lower than -2) should be scanned again the next year and that all patients should have a DEXA scan every two years from the age of 8.

Out of the 27 patients with an abnormal DEXA score, 13 were not seen in the next year (up to 1 year and 3 months later); 7 patients were seen in the next year and 7 patients are not due to have one at the time of collecting the data.

There were 235 DEXA scans undertaken for those who required a biennial review. Out of these 235, 24 scans were not repeated within two years; 133 scans were repeated in the two years after and 77 scans were within the past two years and so are due to have a scan after the date of data collection.

Out of the 96 patients, 37 of these were seen for a first DEXA scan before their 9th birthday whilst 59 were not seen until they had passed the age of 9.

IMPLICATIONS

The recommendations made in this study are being used by the Royal Brompton in their next protocol review to shape their monitoring of bone health within paediatric cystic fibrosis patients. They are changing their guidelines so that scans are taken every eight years instead of every two. The hope is that the number of unnecessary scans being taken can be reduced which would be more convenient for patients and would save the NHS money.

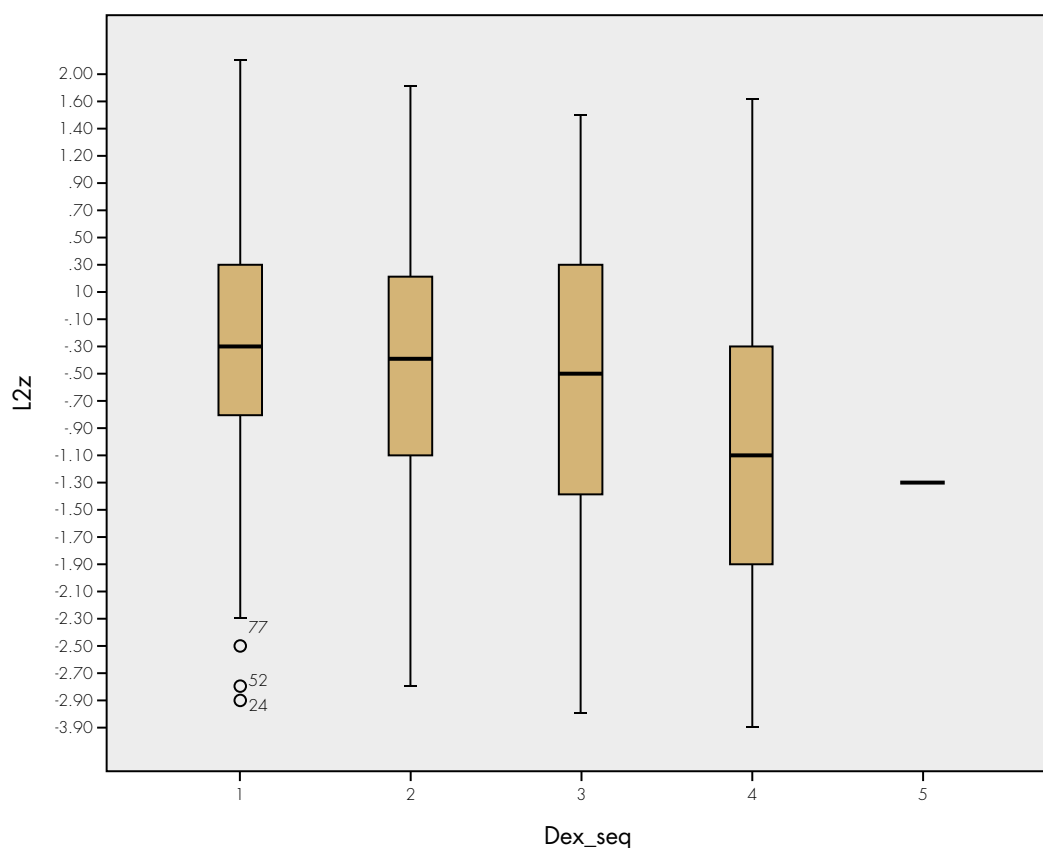


Figure 3 showing the average progress of bone health over the duration of scans. The y axis is L2 (lumbar spine) bone density and the x axis indicates which scan the results were taken from in a patient's development of bone health. A z-score below -2 is classed as being abnormal.



Difference between DEXA Scans	Age difference	DEXA L1-L4 difference	DEXA L2 Difference	Difference in L1-L4 per year	Difference in L2 per year
MEAN	1.95	-0.19	-0.18	-0.11	-0.10
SD	0.62	0.56	0.57	0.30	0.31
LQ	1.83	-0.6	-0.6	-0.30	-0.30
MEDIAN	1.97	-0.15	-0.20	-0.1	-0.1
UQ	2.07	0.1	0.2	0.06	0.10
IQR	0.24	0.7	0.8	0.36	0.40

Table 1 showing the average rates of decline in bone health for L1-L4 and L2 (lumbar spine). A z-score of below -2 is classed as being abnormal.

DEXA sequence	Scan 1	Scan 2	Scan 3	Scan 4	ANOVA sig.
Number	96	87	60	18	
Age in years (mean,SD)	9.98 (1.9)	11.79 (1.8)	13.24 (1.5)	14.34 (1.5)	
M/F	37/59	33/54	25/35	8/10	
L1-4 z-score	-0.12	-0.37	-0.42	-0.96	0.008
L2 z-score	-0.27	-0.48	-0.59	-1.13	0.013
FEV1%	86%	83%	80%	78%	0.174
BMI z-score	-0.03	-0.05	0.04	0.18	0.844
Vit-D	72	69	71	78	0.577

Table 2 showing the development of factors relating to a low BMD in the progression of scans namely lung function, body mass index and Vit-D levels

First DEXA L1-L4 Scan vs FEV1 % Predicted

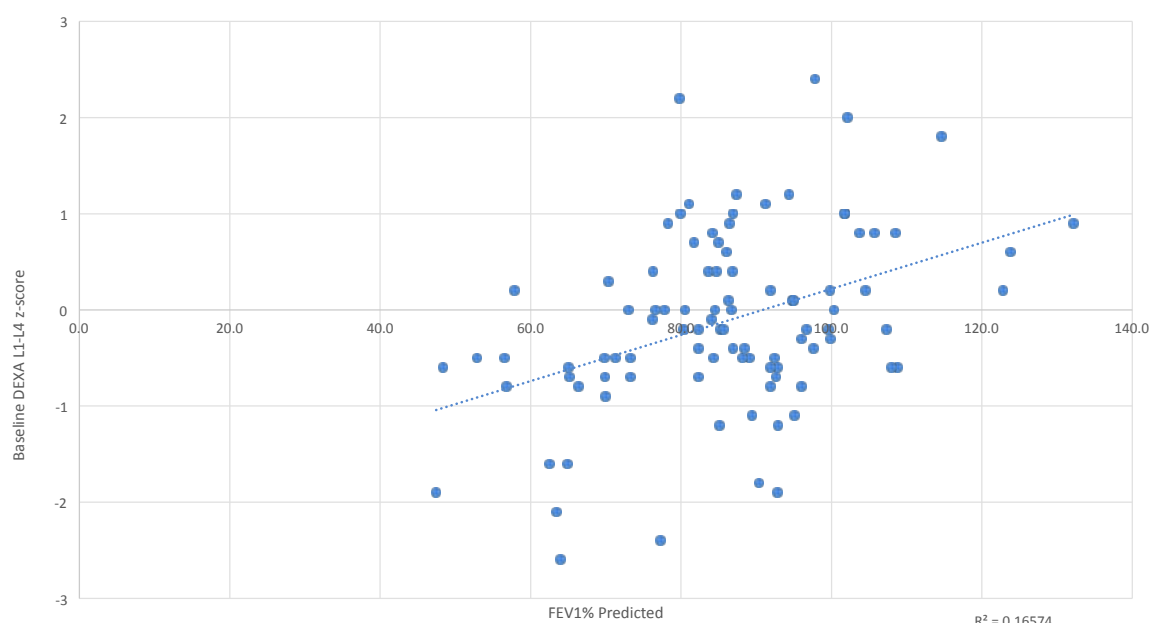


Figure 4 showing the distribution of lung function plotted against the initial bone mineral density scans for each patient





Investigation	Age	FEV1% Predicted	FVC % Predicted	DEXA L1-L4	DEXA L2	DEXA NECK	DEXA FEMUR	Vit D	Corrected Calcium	BMI Z-scores
Mean	10.27	67.85	85.57	-1.73	-2.06	-2.11	-1.59	82.00	2.40	-0.58
SD	±2.37	±13.14	±15.93	±0.89	±1.01	±0.74	±0.92	±29.82	±0.09	±0.93
UQ	11.75	72.12	90.54	-1.60	-2.08	-1.83	-1.15	100.50	2.45	-0.08
MEDIAN	10.54	64.42	85.86	-1.90	-2.25	-2.35	-1.90	92.00	2.42	-0.22
LQ	8.35	63.24	79.50	-2.18	-2.58	-2.63	-2.05	60.25	2.35	-0.86
IQR	3.40	8.88	11.05	0.58	0.50	0.80	0.90	40.25	0.09	0.78

Table 3 showing the mean results from investigations of risk factors at the same time as the initial DEXA scan of those with an abnormal BMD.

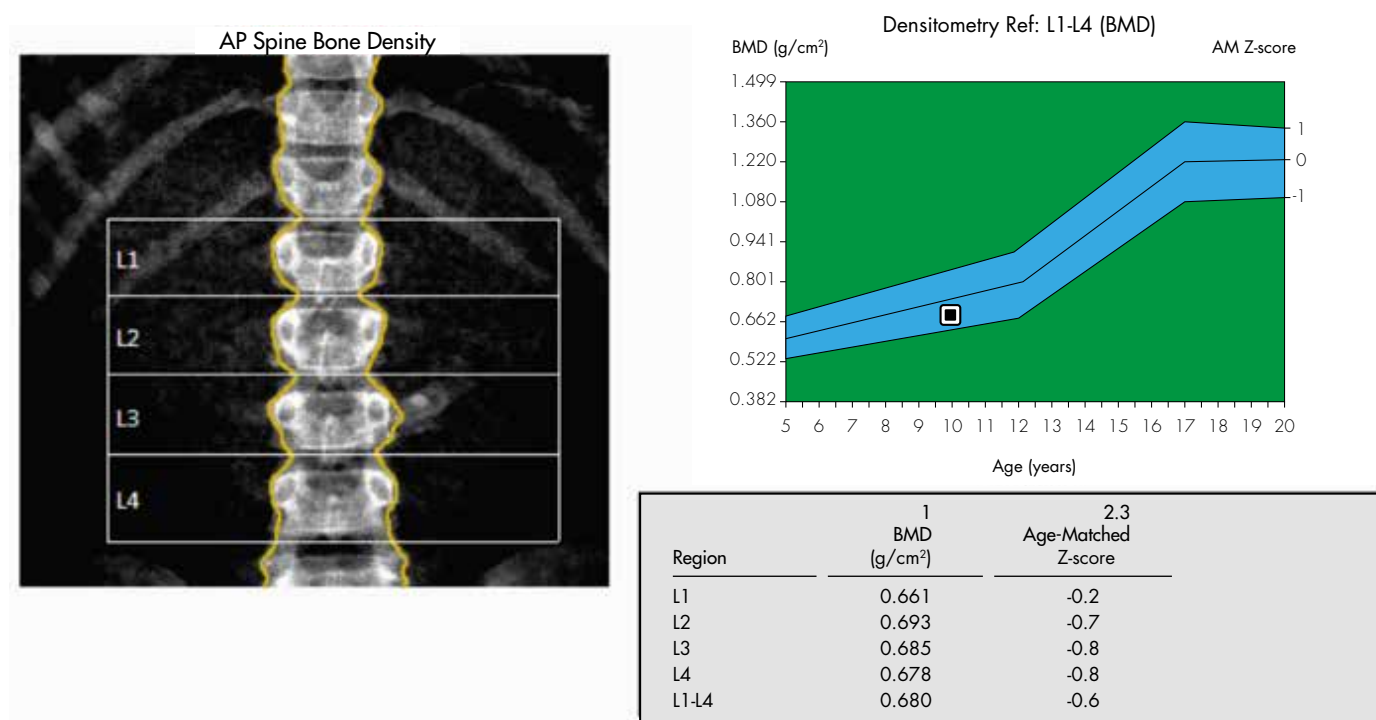


Figure 5 showing the format of a DEXA scan that is stored on the electronic records

Investigation	Age	FEV1 % PREDICTED	FVC % PREDICTED	DEXA L1-L4	DEXA L2	DEXA NECK	DEXA FEMUR	Vita-min D	Corrected Calcium	BMI z-score
MEAN	9.95	87.26	94.24	0.03	-0.11	0.08	0.43	70.77	2.35	0.02
SD	±1.91	±15.31	±12.98	±0.80	±0.85	±1.05	±1.06	±23.57	±0.08	±1.13
UQ	11.05	95.96	103.06	0.60	0.40	0.60	1.00	88.00	2.41	0.70
MEDIAN	9.96	86.78	93.44	-0.10	-0.30	-0.10	0.20	67.00	2.35	-0.07
LQ	8.14	79.88	87.70	-0.50	-0.70	-0.60	-0.30	55.00	2.30	-0.63
IQR	2.91	16.08	15.36	1.10	1.10	1.20	1.30	33.00	0.11	1.33

Table 4 showing the mean results from investigations of risk factors at the same time as the initial DEXA scan of those without an abnormal BMD.





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Was Pericles a tyrant?

Winner of the RGS ILA Competition 2018

Matthew Sargent

Of all the achievements of the ancient Greeks, perhaps the most esteemed by modern scholars is Athenian democracy. For Whig historians, wishing to interpret the past as a progression away from despotism, **δημοκρατία** ('rule of the people') serves as the cornerstone of their historiographical tradition. Often named as a fervent proponent of the democratic model, Pericles has, in times past, been dubbed a foster father of democracy. However, this is to ignore significant evidence, portraying him in a comparably tyrannical light for, when we look at Periclean government, not only do we observe the same imperial aims and populism emblematic of Athens' **τύραννοι** of old, but even a reversion to the same absolutist register, with Thucydides referring to the reins of policy-making being in the hands of "the first citizen".¹ The question remains, of which title is Pericles the more deserving: democrat or tyrant reincarnate?

Historian A. R. Burn is right to divide Pericles' political career into three stages: ascendancy and early years, 'The Age of Pericles', and Pericles' management of the Peloponnesian War. Therefore, in each period, I shall endeavour to evaluate the extent to which Pericles acted (or not) tyrannically. But of central importance is understanding the precise meaning of the word **τύραννος**, on which this essay depends inherently. The word first appears in a poem of Archilochus, in the mid-7th century, where it was most likely a synonym for **βασιλεύς**.² Certainly, when the word appears in Herodotus, it seems to retain much of its original innocence, whilst to the tragedians Aeschylus and Sophocles the value of both words was predominantly metrical, them being used fairly interchangeably. Seemingly, the first definition of the word is attempted by Thucydides, in his discussion of the origins of the tyrannies of central Hellas. Thucydides makes the contrast between, "hereditary kings, having fixed prerogatives,"³ and tyrants, who are not hereditary and whose privileges have no limit. One may note that Thucydides attaches no negative connotations to the word, unlike his successors, specifically Plato, for whom the term smacked of injustice: "it is clear to everybody that there is no city more wretched than that in which a tyrant rules, and none happier than that governed by a true king." (Republic)⁴ For Thucydides, the nature of tyranny boils down to three constituent criteria: unlawful installation of oneself as ruler, limitless power, and, as to the nature of one's reign, that will vary between tyrants.

Equipped with Thucydides' definition, we now turn to the historical evidence itself surrounding Pericles' premiership. Historians such as Henderson argue strongly that Pericles was no tyrant, given that he rose

to power through wholly legitimate channels.⁵ If anything, the story of Pericles' accession was more of luck than brutality. Having spent much of the 460s away on campaign, at the end of the decade, Pericles found himself deputy to the leader of Athens' democratic faction, Ephialtes. Athens' foremost politician, Cimon, in 462, experienced a fall from grace, following his failed mission to Sparta, after which the populace turned against him, and his ostracism paved the way for the ascendancy of Ephialtes and his 'party' – in theory. But within weeks, and most likely motivated by his attacks on the aristocratic Areopagus, Ephialtes was assassinated and Pericles took his place as the leading citizen at Athens. Aristotle and Plutarch both dismiss claims of Pericles' involvement in the murder, pinning the deed rather on some "Boiotian bravo",⁶ Aristodicus of Tanagra, though, for many people, this did little to dismiss their overarching concerns, having someone so young and inexperienced as their de facto head of state. In rising to power through entirely legal processes, Pericles falters decisively at the first hurdle for Thucydides' criteria of a tyrant. The distinction can be drawn between Pericles' rise to pre-eminence and Peisistratos', a tyrant of Athens, who, having crushed the Athenians in battle at Pallene, with his mercenary army eradicated further insubordination and then, "hired bodyguards, [and] raised revenue from various sources."⁷ Peisistratos' violent capture of power distinguishes him from Pericles. However, on another level, Thucydides' definition is, here, somewhat inadequate: can not a man, who gains power democratically, later evolve into a tyrant? Are not 21st century examples, such as Robert Mugabe and Bashar al-Assad, sufficiently indicative of this fact? I would posit that, had Pericles shown conspicuous aspirations towards tyranny, given the contemporary Athenian attitudes, such absolutist practices and behaviours would surely have been an act of political suicide for him.

Perhaps the most persuasive evidence to uphold Pericles' depiction as a democrat is his agenda of democratic radicalism, traceable to the 450s. During his first decade steering the Athenian ship of state, he forced through the assembly vast quantities of democratic legislation: undoubtedly, Pericles' attempt to vindicate the anti-aristocratic perception of him and his 'party'. But, if Pericles had aspired to tyranny, surely it is illogical that he should have pressed for such sweeping constitutional changes, which would inevitably have limited his power. Three bills, in particular, warrant consideration. In 458, Pericles had the chief archonships, hitherto confined to 'knights', opened up to the next taxation class, the *zeugitai* (small farmers), further diminishing the role

1. Thucydides, *History of the Peloponnesian War*, 2.65.10

2. The Greek Tyrants' by A. Andrewes, p.21-22 (1980 edition)

3. Thucydides, *History of the Peloponnesian War*, 1.13.1

4. Plato, *Republic*, 9.576e

5. 'Demos, Demagogue, Tyrant in Attic Old Comedy' by Jeffrey Henderson, p.162 (2013 edition)

6. Plutarch, *Life of Pericles*, 10.7/Aristotle, *Athenian Constitution*, 25.4/'Pericles and Athens' by A. R. Burn, p.46

7. Herodotus, *The Histories*, 1.64.1



of the aristocracy in government. Successive legislation later in the decade authorized that payments be made for public service, first for the jurors (Aristophanes estimates upwards of 6000 jurors in *Wasps*),⁸ then the council, and finally to all citizens designated duties by lot, thus enabling the maximum number of Athens' citizens to participate in her democracy, specifically the poor, for whom pay was almost a prerequisite for participation. The final, and most notorious, reform was Pericles' decree restricting Athenian citizenship. Faced by horrendous overcrowding in Athens, arising from immigration, Pericles suggested that citizenship only be granted to those people whose parents were both Athenian. In reality, an attempt to alleviate the strain on the city's resources, the law was advertised by Pericles as, "an assertion of the sovereign power of the Athenian assembly as the seat of the democracy."⁹ These three laws not only helped encourage pro-democratic sentiment at Athens but also discouraged aspiring tyrants. With much of the population playing an active role in the democracy, any attempt to curb the existing autonomy and power of the institutions of the democracy would have been difficult and dangerous. No doubt, Pericles understood the near impossibility of trying to establish tyranny at Athens and so, even at this early stage, it seems unlikely that reasserting monarchical absolutism for Athens was a primary concern of Pericles.

Modern scholars have commonly ascribed to the period c.461–431 the term 'The Age of Pericles', defined by Webster's Dictionary as,¹⁰ "the most brilliant age of Greek history...standing for one of the highest achievements of civilization." That said, the pre-eminence Pericles enjoyed at Athens was not unheard of. Pericles' actions may have largely dictated Athenian policy for some thirty years but that renders him just one of many 'soldier-statesmen' who came to control Athens amid the 'war fever' of the Persian Wars – men such as Miltiades, Themistocles and Cimon. So there was a definite established precedent that individual men often came to dominate government at Athens. Again, this helps us no further: the most we can deduce is that, to have achieved such pre-eminence, Pericles must have been hugely charismatic, not that he ruled as a tyrant.¹¹

On the other hand, the supremacy that Pericles enjoyed at Athens was wholly different from any that his forebears had experienced. Under Cimon, the spirit of the democracy still burnt brightly, with Ephialtes having been beside him to check his excesses and stress the need for debate in the assembly. With Pericles, the Athenian assembly was fairly at ease in handing to him the reins of administrative power, so we cannot be surprised to see the 'democratic' policy-making process somewhat one-sided in practice. During the period 449–431 (end of the Persian Wars to the start of the Peloponnesian War), Pericles' power reached its zenith. In three characteristics, Pericles' government of Athens bore close semblance to previous tyrannies: his suppression of rivals, populist building programmes and foreign policy. Pericles' most vociferous critic was Thucydides, son of Melesias. Plutarch calls Thucydides, "for a very

long time a political antagonist of Pericles," and we know he suffered ostracism in c.443. Having brought a lawsuit against Pericles on the charge of embezzlement, he underestimated Pericles' control of the assembly and was consequently forced into exile. Plutarch preserves a quip of Thucydides, that, "Whenever I throw him [Pericles] in wrestling, he disputes the fall, and carries his point, and persuades the very men who saw him fall."¹² This remark, of course, refers to the remarkable oratorical skill that Pericles had cultivated, which enabled him to fend off numerous similar plays for power, as attempted by Thucydides. But are we able to confidently call this political system 'radical democracy', when one man had the power to dismiss any opposition that faced him by the mere opening of his lips? Pericles' dismissals of rivals offer interesting comparisons with those methods used by the tyrant Peisistratids in retaining power. Hippias, in his later years, grew increasingly paranoid about ambitious aristocrats, so that, as Herodotus details, he drove the Alcmaeonidae into exile and had the renowned charioteer, Cimon, murdered.¹³ Although Pericles refrained from such violent methods of control, he nevertheless is guilty of having undermined the democratic system through his combatting of his enemies and, like the tyrants, through his marginalization of contentious viewpoints.

Nowadays, Pericles is possibly most celebrated for his alterations to Athens' skyline: reminders of his immense building programmes still litter the cityscape. Pericles believed that a great empire as Athens' was deserving of a proportionately majestic capital and so, commissioning the greatest minds of the day, under Pericles' premiership, numerous constructions were erected, such as the Parthenon, Propylaea and Odeion. Spearheaded by the architect Mnesikles and the sculptor Pheidias,¹⁴ the latter creating a colossal, chryselephantine statue of Athena Parthenos, the end result stood true to Pericles' vision: the crowning glory of imperial Athens. Supporters of Pericles could and did argue that, through the building works, the Athenians were creating an identity, a physical embodiment of their nationalist pride. Cratinus, a comic playwright, however, saw something sinister or ridiculous in Pericles' apparent motivation, declaring, "Behold, our onion-headed Zeus/Approaches, with the Odeion on his crown."¹⁵ The implication of Cratinus' line is that Pericles only undertook the construction works to enhance his own renown: the works both cultivated a sense of self-worth at Athens and massively helped to reduce unemployment. Such populist tactics would have been, without doubt, nostalgic of Peisistratid times for the older members of Athens' population. Like Pericles, Peisistratos' fame lies in his promotion of art and his building programmes. His reign saw the first temple to Athena being built on the Acropolis, as well as the construction of a temple of Olympian Zeus and the Telesterion at Eleusis.¹⁶ Furthermore, the patronage of his sons, Hippias and Hipparchus, attracted poets and musicians from far and wide, including Simonides and Anacreon; this bears an obvious link with Pericles, who is known to have been friends with, if not patrons to, Herodotus, Sophocles and

8. Aristophanes, *Wasps*, line 662

9. 'Pericles of Athens and the Birth of Democracy' by Donald Kagan, p.50 (1990 edition)

10. 'The New Lexicon Webster's Encyclopedic Dictionary of the English Language' – under 'Periclean Athens'

11. https://en.wikipedia.org/wiki/Classical_Athens

12. Plutarch, *Life of Pericles*, 8.4

13. Herodotus, *The Histories*, 5.62.2/Herodotus, *The Histories*, 6.103.3

14. 'Pericles and Athens' by A. R. Burn, p.150, p.153 (1966 edition)

15. Cratinus, *Ploutoi*, Fragment 171.22-23

16. 'Early Greece' by Oswyn Murray, p.229 (1980 edition)



Pheidias.¹⁷ The argument could be made that Pericles just appreciated an underlying attractiveness and effectiveness to the tactics employed by the Peisistratids, helping to generate an identity for the Athenians. More likely, however, is that Pericles recognised a strategy by which to heighten his own prestige and, as with Peisistratos, ensure greater security for his position. One may even say that Pericles' actions, here, could be considered a nascent version of a cult of personality, such as that employed by later dictators, such as Julius Caesar.

The third area of similarity between Pericles' and Peisistratos' reigns are their respective foreign policies. Peisistratos and his two sons, as with Pericles, presided over a dynasty with a strong emphasis on colonisation and the promotion of trade. Peisistratos' adherence to this dual-faceted foreign policy allowed him to reassert Athenian control of Sigeum in the Hellespont, maintain friendly relations with Sparta and Macedon, and even form lasting trading partnerships with parts of Southern Russia via the Black Sea.¹⁸ Pericles, in a similar way, spent much of the 440s/430s consolidating the Athenian empire. His 'Congress Decree' and 'Papyrus Decree' of 449 had laid down the moral foundations for the continued existence of the Delian League,¹⁹ whose purpose was now to, "[rebuild] the Hellenic sanctuaries which the Barbarians had burned down...[and patrol] the sea, that all might sail it fearlessly."²⁰ However, this was only a respectable façade, under which Pericles might exploit the League's member states, forcing them to contribute money or ships. If a member refused to pay its due, the fleet was sent to reimpose order; after Chalcis was reconquered in 446, its population was made to swear an oath,²¹ "not to revolt from the Demos of Athens." Huge payments of tribute were demanded of the allies, as Diodorus notes, saying, "The Athenians, maintaining their claim to sea hegemony brought to Athens...8000 talents."²² Alongside collecting tribute from her Aegean allies, Athens inaugurated a new network of cleruchies (colonies composed of Athenian citizens),²³ by which colonists soon settled on Andros, Euboea and the Gallipoli Peninsula. Athens also founded cities at Thurii and Amphipolis, and strengthened her position in the Corinthian Gulf, forming an enduring friendship with Akarnania. So there were visible similarities between the foreign policies of Pericles and Peisistratos, particularly regarding their pursuit of colonial expansion and trading links. There is one final interesting parallel. Peisistratos could boast the notable and rare feat of not having entered a single mainland war during his reign at Athens. Pericles, in turn, pursued a policy of non-intervention in the years prior to the Peloponnesian War – with considerably less success, of course. Surely it is not just coincidental that both leaders settled on such intrinsically similar foreign policies. On the contrary, Pericles almost certainly used the Peisistratids' policies as the inspiration for his own methods of governance.

Aristotle makes an especially interesting point, writing about the nature of Peisistratos' tyranny, that he was, "more constitutional than tyrannic... kindly and mild in everything." The implication, here, is that, just as predicted by Thucydides, tyranny can be beneficent and even in keeping with the ideals of democracy; instead of destroying Solon's laws and institutions, Peisistratos left them intact, rather concerning himself solely with the elections of his supporters to office. Pericles, however, showed no such respect for the democratic process and, in this respect, we might even suggest that he was more tyrannical than Peisistratos. Pericles, in the opening years of the Peloponnesian War, refused to call any assemblies, until he was forced, whereas Peisistratos showed no such intolerance for meetings of the assembly. So, here, Pericles was behaving more despotically than the actual tyrants.²⁴

By the late 430s, Pericles' tyrannical manifestations had become alarmingly more graphic. Having spent the 440s/430s amassing a vast empire for Athens, and beautifying the city with glorious new public buildings – a visible assertion of her claim to Panhellenic leadership – it was only right, as Thucydides says, that Sparta was so concerned with her neighbour's aggressive expansionism and, as events took a more serious turn in the 430s, Pericles also grew assured of the proximity of war.²⁵ Pericles' skill as a statesman would now be tested to its limit. He joined the Kerkyraian civil war on the side of Kerkyra, in an attempt to destroy Corinthian naval capability (should Athens fight Corinth in a future war), but the snowballing of events was soon out of Pericles' hands. Athens was dragged into campaigns against Potidaea in 432 and an economic embargo over Megara, and before the year was over Athens was at war with Sparta. Here, Kagan's description of Pericles as a "crisis manager"²⁶ is grossly misleading. He was arguably the principal agent provocateur in the descent towards war, for his defence of his policy and his treatment of Sparta and her allies. From Thucydides' writings, historians have found much to support such suppositions: Pericles' provocative speeches to Spartan envoys (1.78), his decree against hearing further peace embassies (1.145.1), and his support of his policy against Megara (1.140.1-2) all constitute excellent evidence.²⁷ During the Peloponnesian War, Pericles refused to allow the assembly to meet, fearing that complaints would be made against him and his policy, likewise marking him out as of a tyrannical disposition. In stark contrast to the conventionally accepted portrayal of Pericles as a democrat, here, we see him having suppressed the views of the demos and conducted government independently of them. If Pericles did overrule popular opinion and take Athens to war, as it appears he did, it appears that Athenian democracy had wholly ceased to function. Aristophanes seems to buy into the idea of Pericles as a tyrant when, in *Acharnians*, he rails at the Megarian Decree as the cause of the war, saying that it, "let loose the lightning, caused the thunder to roll, upset

17. <http://www.grethexis.com/pericles-friends/>

18. 'The Greek Tyrants' by A. Andrewes, p.112 (1980 edition)

19. 'Pericles of Athens and the Birth of Democracy' by Donald Kagan, p.108-111 (1990 edition)

20. Plutarch, *Life of Pericles*, 17.1

21. 'The Athenians and Their Empire' by Malcolm F. McGregor, p.88 (1988 edition)

22. Diodorus Siculus, *Library*, 12.38.2

23. 'Pericles and Athens' by A. R. Burn, p.84-85, p.123, p.136-137 (1966 edition)

24. Aristotle, *Athenian Constitution*, 16.2

25. Thucydides, *History of the Peloponnesian War*, 1.23.6

26. 'Pericles of Athens and the Birth of Democracy' by Donald Kagan, p.218 (1990 edition)

27. Thucydides, *History of the Peloponnesian War*, 2.22.1, 1.78, 1.145.1, 1.140.1-2



Greece.²⁸ Cratinus adds to the abuse, outrightly calling Pericles a tyrant, crudely remarking on Pericles' death that, "The rule of tyranny (has been lifted) and the demos has the power." For comedy to be funny, it must either bear close semblance to reality or be wholly ridiculous (and, here, the latter option is highly unlikely). For comic poets to have voiced such vehement criticisms of Periclean rule is surely suggestive that it did, in reality, function like a tyranny, a one-man show.²⁹

In the course of this essay, I hope to have provided an alternative interpretation of Pericles' pre-eminence at Athens, showing him as having possessed a markedly tyrannic vein, rather than being the committed democrat as he is most regularly displayed. In foreign and domestic policy, as in character, Pericles' government visibly resembled previous tyrannies and his leadership, though not tyranny by Thucydides' definition, nevertheless did not function as democracy. If Pericles disapproved of a certain policy, he would argue against it and, by virtue of his sheer oratorical skill, he always managed to win over his audience. One important question remains: had it been Pericles' aim to establish tyranny? I, for one, have found no evidence to support this claim. On the contrary, Jeffrey Henderson asserts that, at Athens, more so than other πόλεις, the notion of tyranny commanded a reputation of great hatred and suspicion, so that, for the Athenians,³⁰ the tyrant, "became the central negative model of personal and civic behaviour." Evidence of their devotion for and defence of the institution of δημοκρατία can be found in religion and politics. In religion, one of the most prominent cults at Athens was that of the tyrannicides, Harmodius and Aristogeiton, who had assassinated Hipparchus in 514. First honoured in c.510–480 (and then 477/476) with statues in the Agora,³¹ they were even commemorated later in the 5th century by a tomb on the city's outskirts, among the honoured Athenian war dead. It seems that theirs was a veritable cult, proudly preserved by the people of Athens as a reminder of their sufferings under the tyranny. Furthermore, anti-tyrannical sentiment also pervaded much Athenian legislation. Although Solon repealed most of Draco's laws, he conservatively retained his condemnatory attitude towards tyranny and, under his reforms, all citizens aiming at tyranny could be disenfranchised.³² Also, Athens desperately tried to reduce the risk that was posed by tyranny in her colonies, as indicated by the constitution she devised for Erythrai in the 450s³³ by which all aspiring tyrants were outlawed. So, the whole of Athens seems to have been resolutely opposed to a reversion to the days of absolutism. For this reason, Pericles surely had no aspirations for tyranny, considering the impossibility of the task and the danger it posed him. Thus, the only possible explanation for tyranny having evolved at Athens was that it arose subcutaneously, neither intended by Pericles nor resisted by the vast majority of the Athenian population. I, therefore, conclude that, though it had not been Pericles' intention to become a τύραννος, he evolved into one by default, as a consequence of Athenian democracy having ceased to function – the result of Athens' widespread imperial complacency and democratic apathy. Pericles hardly needed weapons to enforce his rule, for his was a tyranny of words, modelled closely on past tyrannies but deriving its credibility from its foundations of democracy.

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*‘It is not knowledge, but the act of learning,
not possession but the act of getting there,
which grants the greatest enjoyment.’*

Carl Friedrich Gauss



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