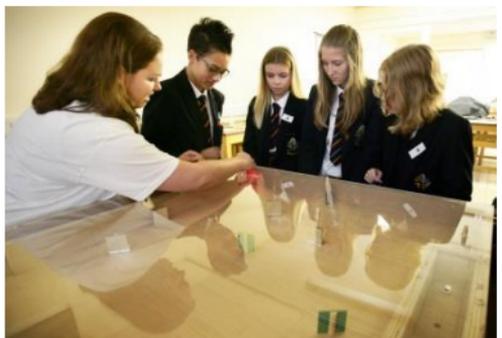




# THE CAVENDISH LABORATORY

## Physics at Work 2016



## Exhibitors List 2017 (in route order)

1. Semiconductor Physics Research Group .....	4
2. The Tech Partnership .....	8
3. Atomic, Mesoscopic and Optical Physics Group (AMOP) .....	14
4. Atomic Weapons Establishment .....	20
5. Quantum Matter Group .....	25
6. Team Crocodile: Fuel-Efficient Car .....	28
7. Earth Sciences (Dept. Of) .....	32
8. Mathworks .....	34
9. Optoelectronics Research Group .....	37
10. Astrophysics Research Group .....	44
11. Rolls-Royce .....	47
12. Material Science & Metallurgy (Dept. Of) .....	52
13. BP .....	55
14. Fracture and Shock Physics Group .....	59
15. Isaac Physics .....	63
16. Biological and Soft Systems Research Sector .....	67
17. Computational Radiotherapy .....	71
18. British Antarctic Survey (BAS) .....	77
19. Marshall Aerospace and Defence Group .....	81
20. Laboratory for Scientific Computing .....	85
21. Dr Jane Blunt .....	88

**We would like to thank everyone who has given their time and expertise so generously to this event.**



# THE CAVENDISH LABORATORY

&

THE CAMBRIDGE PHYSICS CENTRE

Present the

2016

**PHYSICS AT WORK EXHIBITION**

at the Cavendish Laboratory,  
Madingley Road, Cambridge

On

**Tuesday 20<sup>th</sup> September**

**Wednesday 21<sup>st</sup> September**

**Thursday 22<sup>nd</sup> September**

**Organised by:**

Dr. Lisa Jardine-Wright and Jacob Breward Butler  
Educational Outreach Department, Cavendish Laboratory

**Facilities and Technical Assistance:**

The Cavendish Laboratory

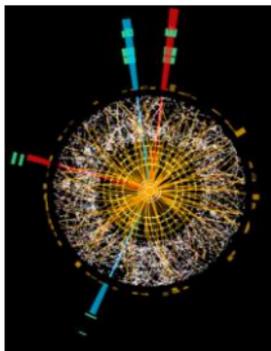
**Also sponsored by:**



## PHYSICS AT WORK 2017

### Exciting discoveries

The Physics at Work Exhibition showcases many uses of physics in everyday life, along with applications of physics in research and industry. During your visit you will have the opportunity to gain first-hand experience of what is happening in the world of science today. Each of the exhibits will be presented by people working at the cutting-edge of research and development; please do not hesitate to ask them any questions you like – the exhibitors are here to provide answers!



### Looking to the future

Many of those that have attended Physics at Work Exhibitions in the past have gone on to have physics-based careers in industry, commerce and research. If you are already thinking about a career in science, technology or engineering, the exhibition will give you some further ideas about the kind of jobs you can do if you have qualifications in science.

Inside this booklet, alongside the information about each exhibit, you will see a short profile of some of this year's presenters. Each profile includes information about their education and training, what their job involves on a day to day basis, and other careers that they have had or considered along the way. Take a few minutes to have a look at the breadth of opportunities available to physicists.

If you don't intend to take up science professionally, a visit to the Physics at Work Exhibition may still be fascinating and valuable. We are all influenced on a daily basis by scientific discoveries and advances – the first compact disc players and TV mobile phones were demonstrated at Physics at Work Exhibitions!

The 2017 Physics at Work Exhibition will give you an insight into the next generation of scientific achievements – have fun!

For more information about the types of jobs you can do if you have scientific qualifications visit: <http://www.physics.org>



## **1. Semiconductor Physics Research Group**

<http://www.sp.phy.cam.ac.uk>

Electricity seems very simple – you just flick a switch and there it is – but how often have you thought about what is happening to the electrons that make up that electricity? The electrons' behaviour can change depending on what material they are in. Materials can be divided into three categories according to their ability to conduct electrons: insulators, conductors and semiconductors. In insulators, such as rubber and plastic, charge does not flow at all. In conductors, such as metals, electric charge can flow easily. In semiconductors, such as doped Silicon, the ability of the material to permit charge flow can be controlled. Thus semi-conductors can range from insulating to conducting. This can be very useful; computer processors are based on the ability to switch currents on and off quickly. Semiconductor transistors are well suited to this task, as they are able to go from conducting to insulating by simply applying a small voltage to a special terminal.

In the Semiconductor Physics group, we design, make and carry out experiments on new kinds of electrical devices to find out how electrons behave, and how we can control them. In the larger scope, beyond academic research, our work leads to faster, more energy efficient semiconductor devices and even brand new devices.

### **Few dimensions and quantum mechanics**

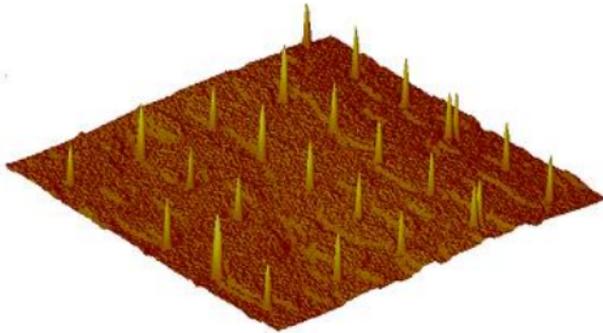
Our group specialises in the physics of electrons confined to two, one or zero dimensions. Electrons can be made to travel in two dimensions by stacking layers of different semiconductors, effectively trapping the electrons at the boundaries between the layers. We can also apply electric fields to the stacked layers of semiconductors to force the electrons to travel along only one direction (1 dimensional) or not allow them to move in any dimension at all (0 dimensional), which gives us quantum dots.

Some of us study low dimensional electron transport in semiconducting materials that naturally show one- and two-dimension properties, such as GaAs/AlGaAs heterostructures, and graphene (single layers of graphite). Others in the group investigate how layered semiconductor structures turn

electrons into photons (light particles), in particular making lasers that work at wavelengths not easily produced by the usual methods.

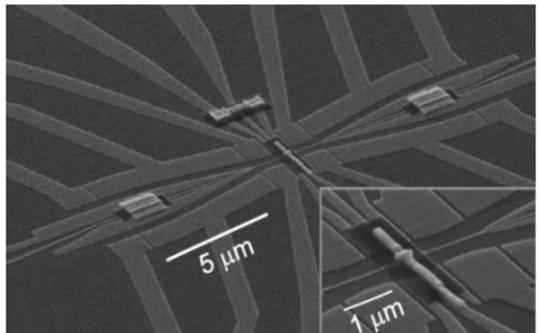
← **Figure 1:**

*An array of InAs quantum dots growth by MBE technique. By apply an electric field, the electrically driven single-photon source is generated*



**Figure 2:** →

*A surface-acoustic-wave electron interferometer, created using electron-beam lithography. This method can be used to create features at a nanometre level. The thin "fingers" of metal are over 1000x thinner than a human hair.*



However we do it, the electron behaviour is very different compared to that in three dimensions. Quantum mechanics starts to take over from classical physics, with lots of strange effects such as quantisation (measured quantities can only be multiples of a certain value) and wave-particle duality (for example, electrons creating wave diffraction patterns).

## Fabricating new kinds of device

The devices we make have to be very small, down to just a few millionths of a millimetre high or wide. This is about a thousand times smaller than a dust particle, so they have to be fabricated in a clean room where virtually all the dust particles have been removed.

Layered structures are deposited a single atomic layer at a time by molecular beam epitaxy (MBE), where a beam of particles is fired at a pre-grown crystal with a known configuration of atoms on its surface. This is done in an ultra-high vacuum so that unwanted atoms do not change the properties of the finished structure.

**Name:** Mrs Melanie Tribble

**Position:** Research Associate

**Company:** Cavendish Laboratory

**Educated at:** Lordwood Girls' School, Birmingham

**A-levels:** Physics, Chemistry, Maths, Computer Studies

**University:** St. Hilda's College, Oxford

**Qualifications:** BA Hons Physics

**Current job:** 1992-date Semiconductor Physics Group, Physics Department, University of Cambridge. I am responsible for the maintenance of the SP cleanroom including repairing equipment, ordering supplies, managing cleanroom suits and helping people outside of SP who want to use our cleanroom. I also assess the quality of gallium arsenide wafers grown in SP's molecular beam epitaxy systems by making and testing devices from them.

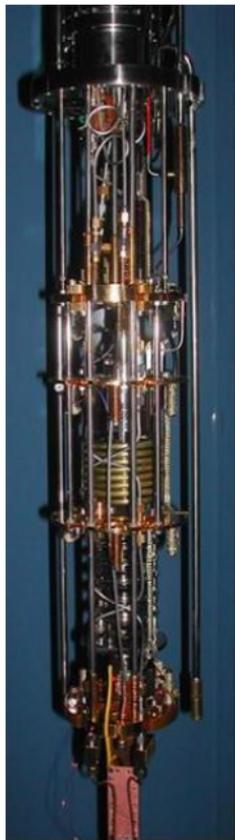
**Previous job history:** 1989-1991 Account Representative, Dorothy Millman Marketing Services, Toronto, Canada. I spent two years promoting store credit cards.

1986-1989 AEA Technology, Harwell. I worked in the Solid State Chemistry Group of the Materials Development Division. The work of this Group consisted of the development of solid state gas sensors, batteries and optics. I worked principally in the area of fibre optics.

**Interests:** I collect antique vesta boxes and old postcards. I enjoy making dolls' house miniatures and I can occasionally be heard ringing church bells.



## Measuring at very low temperatures



← **Figure 3:** A dilution refrigerator, one of the pieces of experimental apparatus we use to measure our devices at very low temperatures. This image is labelled with the temperature each part of the fridge reaches (absolute zero = 0K (Kelvin), one mK = one thousandth of a degree Celsius). Devices are mounted below the bottom of the picture.

Most of the experiments we do in Semiconductor Physics are resistance measurements, in which we observe the effects of magnetic and electric fields, temperature changes, and AC voltage frequencies on the electrons flowing through our devices.

At higher temperatures, quantum mechanical effects on the measured resistance are overshadowed by the contribution from electrons colliding with the oscillating nuclei of the material. In order to see quantum mechanical effects, we have to cool our devices down to very low temperatures, usually between a few thousandths and a few hundredths of a degree above absolute zero. To get to such low temperatures, measurements are carried out in cryostats, which are essentially very efficient refrigerators that use liquid nitrogen and liquid helium as refrigerants. By observing how electrons behave under certain electric and magnetic fields at low temperature we can use the scientific method to work towards bringing this behaviour towards room temperature.

University of Cambridge

## 2. The Tech Partnership

<http://www.ttp.com>



### Innovation

The Technology Partnership, TTP, was founded in 1987, and for over 25 years has established a reputation as Europe's leading independent Technology and Product Development organisation.

TTP has been responsible for some world-leading developments in fields as diverse as wireless communications and digital printing through to drug delivery.



We work in partnership with our clients to bring new products to market, creating new business from advances in technology. We are co-operating with some of the most famous companies in the world – companies that share our vision and understand the true value of intellectual property. Companies like: Airbus; Bayer; Cadbury Schweppes; Fuji Film; GSK; Hewlett Packard; Philips; Panasonic; Unilever; Xerox and many others, too numerous to list.



Physicists play a major role at TTP, and can work on a wide range of projects from printing and laser technology through to confectionery packaging.

## Electronic Aerosols

One example of physics at work is TTP's development of 'electronic aerosol' technology and products based upon it. Conventionally an aerosol is produced by ejecting a liquid at high velocity through a fine nozzle. The flow is turbulent causing small localised pressure fluctuations in the liquid; and these lead to the break-up of the jet into a stream of small droplets of relatively uncontrolled droplet size. In domestic spray products, such as aerosol cans, the liquid ejected is typically a solution of a product (e.g. air freshener, insecticide) in a high vapour-pressure propellant liquid. This is environmentally unattractive.

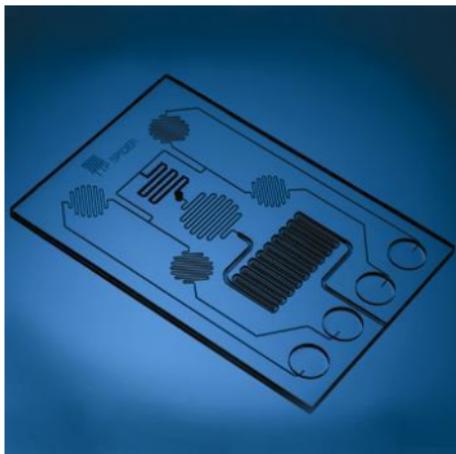
By contrast, TTP's 'electronic aerosol' technology employs a piezoelectric actuator to oscillate a perforated membrane, contacting the liquid to be sprayed, at ultrasonic frequencies. The high frequency oscillation causes oscillatory pressure fluctuations that eject the liquid through the holes. One droplet is ejected per hole per cycle. Using many holes creates a strong spray. The droplet size is primarily determined by perforation size. The result is a low velocity spray of droplets of very well controlled size and direction without the use of harmful propellants.



Applications range from drug delivery to consumer products such as hairspray and deodorant.

## Microfluidic Technology

A second example of physics at work is TTP's microchemistry platform, a patented microfluidic system that allows complex applications of laboratory biochemistry to be undertaken on a miniaturised, low cost disposable card. By harnessing cutting edge micro-fabrication methods and knowledge of fluidic flow on a micron scale, such devices are becoming a reality and enable small handheld portable diagnostic systems. Used in Ambulances and GP surgeries, these devices will allow early detection of time-critical illnesses such as heart disease.



**Name:** Tracey Brown

**Position:** Director of Marketing

**Company:** TTP Meteor Ltd

**Educated in:** USA, UK

**University:** University of Cambridge, University of Northern Colorado

**Qualifications:** BA (Physics, Mathematics, Music), MBA (Management)

**My day to day work involves:** Promoting our products to customers and business partners at conferences and trade shows, online and through the press. Understanding the competitive environment and working within a team to set the direction of the business.

**Other experiences/previous professions:** Board Director, Business Developer, Engineer. I've been involved with starting companies, running companies, selling companies and closing companies.

**The best thing about my job is:** World travel.

**The thing I like least about my job is:** Never having enough time.

**Other careers considered:** Orchestral Musician, Secondary Maths Teacher



**Name:** Rob Cook

**Position:** Consultant Engineer

**Educated in:** Reading School, Berks

**A-Levels:** Maths, Further Maths, Physics, Design and Technology

**University:** Sidney Sussex College, Cambridge

**Qualifications:** MEng (Hons) Engineering, CEng MIET

**My day to day work involves...** designing electronic systems from inhalers to radar systems and everything in between. Sometimes I'm working at my desk designing circuits, or possibly modelling some part of the system. The next day I might be in the lab working on some hardware that I've designed, helping to integrate it into the rest of the project, working alongside engineering and scientists from other disciplines (makes me learn a lot!). I also get to work closely with our clients to help them to get the best outcome from projects.

**Other experience or previous professions:** Antenna engineering at a defence company.

**The best thing about my job is...** having responsibility and accountability for getting the job done in the best manner.

**The thing I like least about my job is...** big sets of documentation for large clients after the main engineering challenges have been completed.

**Other careers considered:** research engineer



**Name:** Dr David Cottenden

**Position:** Consultant Physicist

**Educated in:** St Thomas More and Sharnbrook Upper Schools, Bedford

**A-levels (or equivalent):** Maths, Further Maths, Physics, Chemistry

**University:** Churchill College, Cambridge

**Qualifications:** MA (Cantab) physics / maths, MMath, PGCE secondary maths, PhD in biotribology

**My day to day work involves...** translating the business needs of clients into practical requirements for medical devices and development projects, and the practical limitations and possibilities into business opportunities. Technically, this involves coming up with good ideas which avoid complexity, and enabling informed decisions with well-targeted experiments and theoretical work.

**Other experience or previous professions:** academia, teaching.

**The best thing about my job is...** is the variety and the impact that my ideas and work can have.

**The thing I like least about my job is...** when we can't agree terms with a client, and a great opportunity is missed.

**Other careers considered:** Teaching and academia!



**Name:** Richard Gold

**Position:** Consultant Engineer

**Educated in:** Newent Community School, Gloucestershire

**A-Levels:** Maths, Further Maths, Physics, Chemistry and Fine Art

**University:** University of Warwick

**Qualifications:** MEng (Hons) Electronic Engineering with Communications

**My day to day work involves...** in consultancy there are always multiple projects running at the same time and since the sectors in which we work are so wide each day is different. As an example yesterday morning I was working on wearable electronics trying to minimise the power consumption to allow it to run on a small battery for days, in the afternoon I'm designing a medical electromagnet that is drawing twenty-thousand times the power to generate strong magnetic fields.

**Other experience or previous professions:** As part of a university programme I worked with the European Space Agency on an atmospheric probe that was launched on a rocket into space last year from Sweden

**The best thing about my job is...** working with a diverse group of scientists and engineers who are always happy to help and share their experience

**The thing I like least about my job is...** having to clear my desk when the pile of electronics, paperwork and coffee mugs gets to high

**Other careers considered:** I almost applied to Art College instead of university, but the good working hours at TTP means I can still sketch/paint in my free time



**Name:** Thomas Brown.

**Position:** Consultant.

**Educated at:** Reigate Grammar School, UK.

**A-levels (or equivalent):** Maths, Physics, Chemistry, Electronics, Economics.

**University:** University of Bath.

**Qualifications:** MEng (Hons) Integrated Mechanical and Electrical Engineering.

**My day to day work involves...** Developing novel devices to meet client needs. This can involve taking a base scientific concept and developing it into a useful device, or taking pre-existing devices and combining them in a new, inventive, manner. A lot of my time is spent in the laboratory making concepts and conducting experiments to prove the device operates as we expect. Much of my work involves using embedded electronics and software, and is spread out over many different industries. **Other Experience or previous professions:** Aerospace Engineer at Rolls-Royce Plc.

**The best thing about my job is...** The variety of problems I can encounter day to day requires me to have an extremely broad technical knowledge and allows me to constantly learn something new. No two days are the same.

**The thing I like least about my job is...** Much of the work we do is driven by clients

**Other careers considered:** Teaching and academia.

**Name:** Rob Selby

**Position:** Consultant Engineer

**Educated in:** Newtown High School, Powys

**A-Levels:** Maths, Further Maths, Physics, Chemistry, General Studies

**University:** Peterhouse, Cambridge

**Qualifications:** MA (Engineering), CEng MIMechE



**My day to day work involves...** Managing activities of the development team, defining needs with the client and keeping them informed of progress. I also spend time; discussing problems with the project team and identifying potential solutions; conducting experiments; doing calculations; sketching concepts and designing mechanical systems in CAD; looking for suppliers for key new components or ways to manufacture parts of the product; writing patent applications and working out how to defend them when they are being examined.

**Other experience or previous professions:** A number of roles with BOC (British Oxygen) working in the design office, introducing telemetry to the business, working on a production site and managing installations of gas equipment on customer sites.

**The best thing about my job is...** the opportunity to solve difficult problems and make new and better products and technology

**The thing I like least about my job is...** big sets of documentation for large clients after the main engineering challenges have been completed.

**Other careers considered:** engine design

### 3. Atomic, Mesoscopic and Optical Physics Group (AMOP)



#### Bubbles Bubbles

Why look at bubbles? Bubbles are not only beautiful and fun, but also formed with smart mathematics! The few-atom soap molecules that bubbles are made of coordinate together in the most efficient ways to make the shapes that we can see every day, and can teach us a lot about how form and patterns emerge in nature.

#### Spherical Soap Bubbles

Have you ever wondered why bubbles are spherical? Maybe you have, or maybe you haven't. In any case, it doesn't seem surprising, does it?

We are used to nature presenting us with smooth, spherical shapes...This must have a deeper, more fundamental meaning. A sphere can be perfectly described by an extremely simple mathematical formula. But, why are natural objects so mathematically perfect?

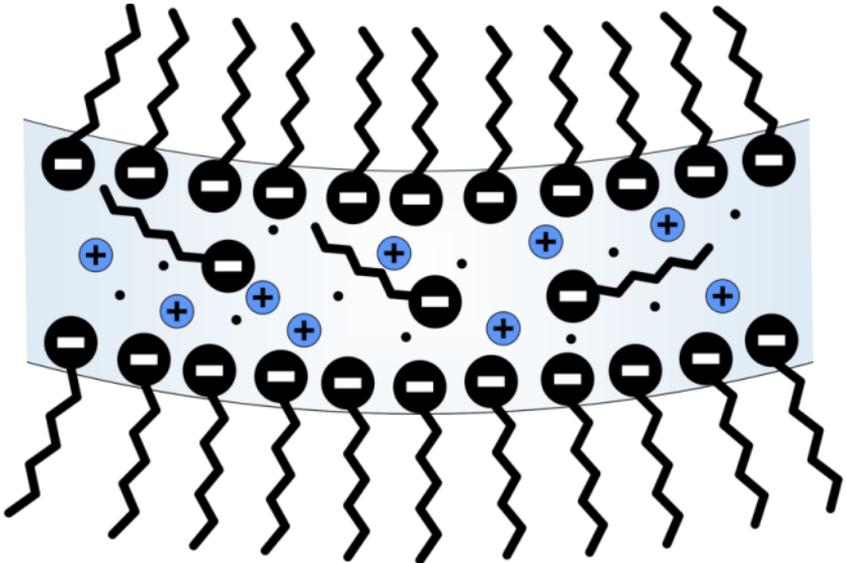


#### Surface Tension - minimal surface area

The way the molecules arrange determines their macroscopic shape very precisely... Bubbles have air inside, and extremely thin walls made of soap and water molecules – these walls are 100 times thinner than a human hair! All the soap molecules line the two surfaces of the film, with their long tails out, since these are repelled by water molecules. The soap molecule heads however, are pointed inwards into the film, since they are attracted to the water molecules

inside it, which hold everything together. This force grouping all molecules together is called surface tension.

The more surface, the more surface tension, and this costs energy! Like everything in nature, bubbles try to minimize the energy they have to spend to survive. And, guess what the geometric shape that has the smallest surface is? That's right, spheres!



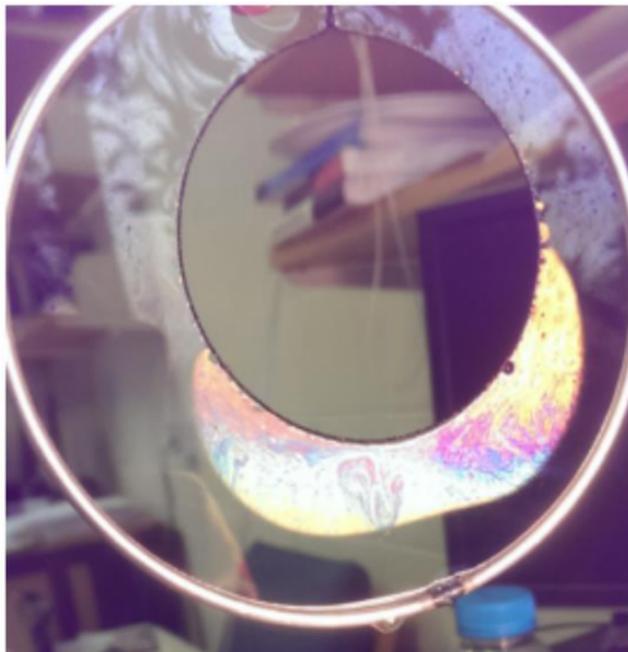
The pressure inwards exerted by the film is exactly cancelled by the pressure exerted outwards by the air inside. If you keep blowing air into your bubble, it will expand: increasing its surface, and hence increasing its overall tension to counteract that of the air. But that also means the film will get thinner and thinner, as there is only so much soap and water in it...

But, why don't they just form droplets?

And, why do we see soap moving around the surface in different concentrations?

Can you make a hole in a bubble?

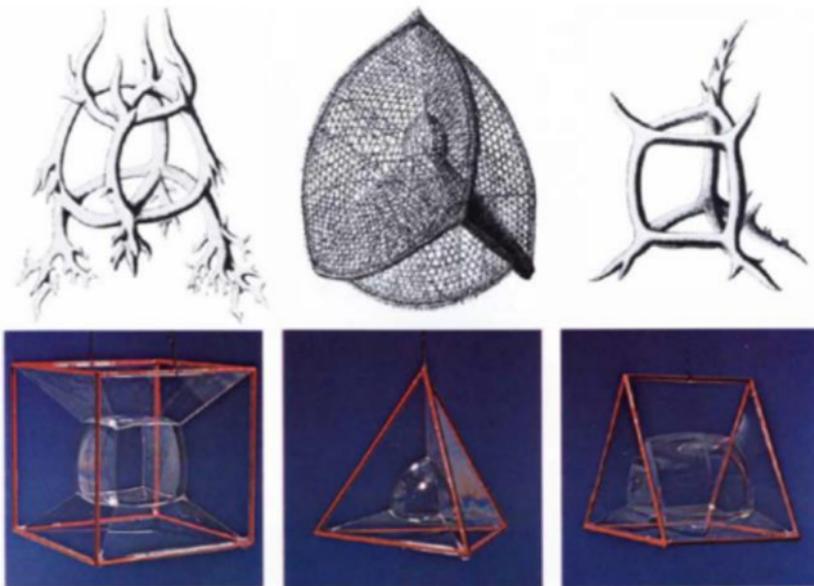
How big is this surface tension? Can we feel it pulling back in our experiments?



And... why are these films iridescent?

### **Bubbles in Frames and the Bubble Computer**

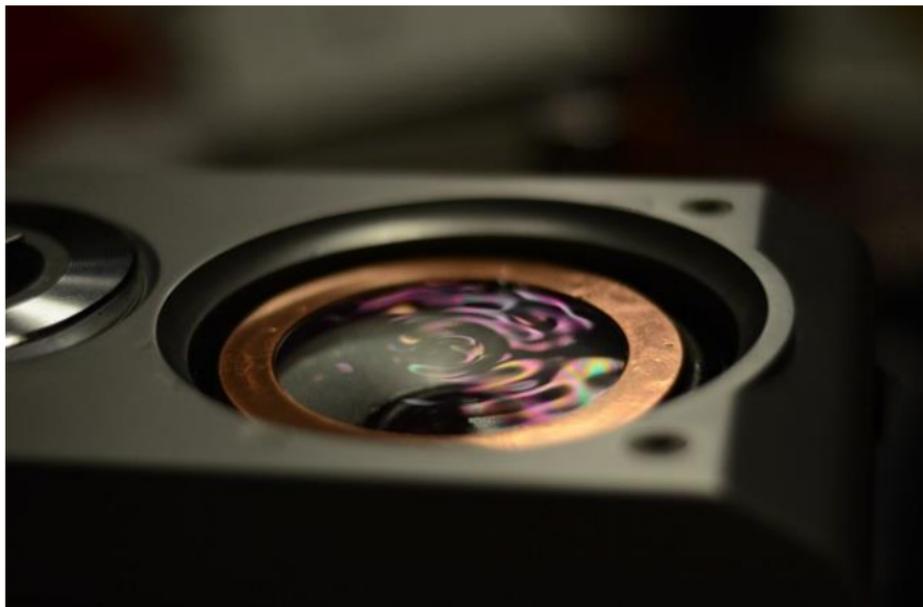
Now that we know bubbles can find the configurations with the smallest areas... we can use that to find out things about shapes! We can test this using frames of different geometries... could you imagine that the tetrahedron is not completely square? Or the cube? The bubble tells us that a tetrahedron is not quite the minimal shape for this frame. We were not the first ones to realise this... Nature already did! If you look at the shapes of microscopic plankton (radiolarians) you will find the same concept being echoed in their form...



But we can go further... with a bubble, we have a tool that cannot fail at finding the most energy efficient configuration. And it's fast at doing so! Couldn't we use it to solve problems – just like a computer does?

There is a very interesting problem that is actually all about this... the Steiner problem, otherwise known as the motorway problem. What is the fastest interconnect between several places? We have a tool that will help you find the shortest way possible to link together all the cities in Britain using only soap bubbles!

## Movement: Bubble Drum + Sound



What happens if you leave a bubble alone? Does it stay there forever? Can it move?

What about if you interact with it? Because of the Marangoni effect a bubble is elastic - it can dance in response to a sound wave driving it, forming resonances that you can see via the light reflected from it.

We will play sound waves on our bubbles using loudspeakers, and use different frequencies together or separately to watch the resonance patterns that they form – just like the resonances on a guitar string (1D), but this time on a surface (2D)!

We can “see” the sounds... higher frequency (higher pitch) will result in patterns with shorter wavelengths!



When not playing with bubbles we are optical physicists who study the interaction of light and matter at the quantum scale. We’re trying to work out how to use the fascinating phenomena that emerge in these systems to build new technologies that can communicate and process information in entirely new ways. We also are searching for new ways to sense the world around us with nanometre-sized probes. Maybe we can use tiny diamonds to measure dynamic processes inside of a living cell! Importantly, the same relationship between mathematics and observation we can see in the soap bubble is what we build our investigations on every day.

## 4. Atomic Weapons Establishment



<http://www.awe.co.uk>

The Atomic Weapons Establishment (AWE) plays a crucial role in the defence of the United Kingdom by providing and maintaining the country's nuclear deterrent. It also has a key role in supporting the Comprehensive Test Ban Treaty, counter terrorism and the country's national nuclear security. It is a centre of scientific and technical excellence, with world-leading facilities.



Photos by LA(phot) Mez Merrill and LT Stuart Antrobus RN

### Systems Safety

To prevent a misfire AWE builds a number of safety mechanisms into a system and these can incorporate a number of different physics phenomena.

We are going to show you the difficulty of releasing a safety mechanism with lasers, working together as a team to complete the experiment to allow the electromagnetic cannon to fire. Hopefully we will all have some fun learning about lasers and electro magnets in this interactive demonstration.

*You must solve the laser maze to allow the cannon to fire*

*There are two competing systems. Your mission is to fire your system before the other team!*

## **Lasers**

The word laser is an acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. Lasers are used in a wide variety of applications, including CD/DVD players, high end optical electronics and physics experiments undertaken at AWE.

Lasers can have low energy compared to a standard lightbulb of 60 Watts (W) but they focus all of their energy on a very small area. This makes them ideal for applications that require a very high energy-density.



Increasing the energy (and energy density) allows lasers to be used for different things. The power of a typical laser pointer is around 1mW, and the laser in a CD/DVD player delivers roughly 5mW. Lasers can also be used for surgical applications delivering around 30W to 100W and in industrial applications lasers can even cut metal with outputs as high as 3000W. In contrast, facilities such as the Orion laser at AWE can deliver power outputs of the order of Peta Watts (1,000,000,000,000,000 Watts!)



The high energy-density conditions generated by the Orion laser allow scientists to study matter in states not easily obtainable on Earth. At these very high temperatures and densities materials become plasmas and interact differently. This allows plasma physicists to study the thermonuclear reactions that take place in stars, but on a much smaller scale.

## **Electromagnetism**

Electromagnetism is one of the most important physics phenomena of the modern age. Without it large scale electricity production, modern computing and scientific research would be impossible.

When an electric current is passed through a wire, a magnetic field is created. The strength of the magnetic field can be increased by winding the wire around a ferromagnetic material (materials that can be magnetized such as iron). The magnetic field can also be made stronger by increasing the current passing through the wire. Large scale electricity, such as in a nuclear power plant is produced by spinning an electromagnet coil in a generator at over 1500 RPM (Rotations per minute).

It also plays a major component in modern computing. Where electromagnets are used to write and read information in binary digit form onto hard drives.

At AWE we use electromagnets in our particle accelerator experiments. By sending pulses of current we can accelerate particles to extremely high velocities. When particles are travelling this fast they lose their electrons and we can study their nucleus. Particle Accelerators can also be used to study the fundamental structure of matter – The Large Hadron Collider at CERN uses this technique.

**Name:** Jack

**Title:** Graduate Cost Engineer

**A-Levels:** Maths, Business Studies, Economics

**Qualifications:** BSc in Mathematics

**My Day to Day Job Involves:** Delivering projects within an agreed cost and time constraints.

**Best thing about my job:** Seeing how multi-million pound projects are organised and controlled using the same management principles, whilst developing new ways of working in order to further streamline project performance.

**Name:** Matthew

**Title:** Analytical Scientist

**A-levels:** Chemistry, Biology, Psychology

**Qualifications:** BSc Hons Chemistry

**My day-to-day job involves:** Scientific analysis and reporting data.

**The best thing about my job is:** Collaborating with experts in the field, drawing from their many years of collective experience, to learn new and innovative ways of analysing inorganic elements.

**Name:** Matthew

**Title:** Warhead Mechanical Design Engineer

**A-levels:** Physics, Maths, Further Maths, ITC

**Qualifications:** MEng Motorsports Engineering

**My day-to-day job involves:** Design and develop components and systems, and writing technical reports.

**The best thing about my job is:** Seeing my designs go through to production and being able to network with so many people with different expertise in many fields.

**Name:** Connor

**Title:** Production Design Engineer

**Highers:** Maths, Physics, Chemistry, Geography, Engineering Drawing

**Qualifications:** MEng in Mechanical Design Engineering

**My Day to Day Job Involves:** Design and developing components, implementing scientific and safety testing.

**Best thing about my job:** Seeing my ideas and drawings being made into real objects, getting to use interesting technology such as 3D Printing

**Name:** Matthew

**Position:** Safety Assessment Specialist

**Highers:** Mathematics, Physics, Chemistry, English, Product Design

**Qualifications:** MSci in Applied Chemistry and Chemical Engineering

**My day-to-day:** Developing documents which help to keep everybody safe and prevent damage to equipment or products.

**Best thing about my job:** I get to learn about and experience a vast array of technologies that are integral to the continued availability of the product

## 5. Quantum Matter Group

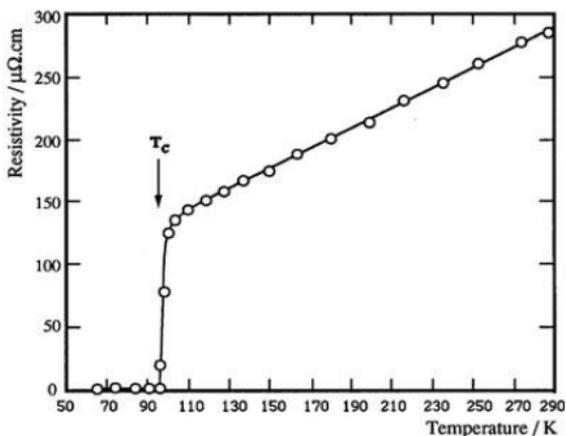


<http://www-gm.phy.cam.ac.uk>

### What is superconductivity?

In 1911, at Leiden University in the Netherlands, Professor Onnes was cooling down mercury with the newly discovered cryogen, liquid helium, and measuring its resistance. When the temperature reached 4.15 K [-269 °C] the electrical resistance suddenly dropped to zero. After a lot of checking, this result was found to be correct, and the effect was called superconductivity. Many other superconducting materials were discovered over the next 75 years but none of them was found to be superconducting above 23 K [-250 °C].

Discoveries made in the past 25 years have raised superconducting transition temperatures to a much higher value. Scientists at the University of Houston first synthesised a ceramic compound containing yttrium, barium, copper and oxygen, which becomes superconducting at 93 K [-180 °C]. Its chemical formula is  $\text{YBa}_2\text{Cu}_3\text{O}_7$  although the material sometimes loses oxygen.



↑ **Figure 1:** The variation in resistivity of  $\text{YBa}_2\text{Cu}_3\text{O}_7$  with temperature.

Figure 1 shows the sudden disappearance of the resistivity of  $\text{YBa}_2\text{Cu}_3\text{O}_7$  on cooling the sample. Other ceramic compounds containing copper also give high transition temperatures. The cuprate superconductor with the highest transition temperature is  $\text{HgBa}_2\text{Ca}_2\text{Cu}_3\text{O}_{8+d}$ , which shows superconductivity at 160 K [-110 °C] under pressure.



↑ **Figure 2:** A  $\text{YBa}_2\text{Cu}_3\text{O}_7$  superconducting disc being “levitated” by a permanent magnet.

These newer ceramic superconductors are known as High Temperature Superconductors, and are superconducting in liquid nitrogen, which is much cheaper than liquid helium - however being ceramics, like a teacup, they are brittle.

## Why is superconductivity important?

If you pass a current along a normal copper wire, energy will be lost because the wire has a resistance. If the wire is a power cable this loss is significant. In fact 1.5% of the power generated in the UK is lost in transmission. This is significant but the real problem is that if you do not want your wires to melt you have to dissipate this heat. Superconductors do not have any resistance so there is no heat to dissipate; this means that you can put much more current in the same space. This property of superconductors can be exploited to increase the capacity of cables in the centre of a city, without having to dig up the road.

To make a strong electromagnet you also need a very large current in a small space, therefore, superconductors are very suitable for making electromagnets. Superconductors also have the advantage that once you have a current, they do not use any power. However, superconductors do have disadvantages. You have to cool them down to between  $-200^\circ\text{C}$  and  $-269^\circ\text{C}$ ,

and the high temperature superconductors are brittle ceramics, which means making wires from them is challenging.

Superconducting magnets are used in MRI scanners, mineral separation machines, and recently in high power compact electric motors for powering large ships.

Superconductors interact with magnetic fields in interesting ways, which allows them to be used to make very sensitive magnetic sensors, and high frequency microwave and terahertz receivers. They can also be used for very high frequency electronics and possibly for quantum computing.

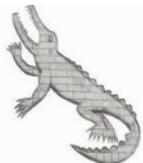


↑ **Figure 3:** A Magnetic Resonance Imaging machine (MRI)

### Promising applications of High Temperature Superconductors:

Superconducting component	Benefit	Market/Application
Resonators, filters, delay lines	Well controlled, high frequency circuits	Communications
Magnets, cables, windings	High current density	Use of electrical energy
Scientific/medical instruments	Sensitive control and creation of magnetic fields	Study of materials, geology and medical patient imaging.

# 6. Team Crocodile: Fuel-Efficient Car



<http://www.teamcrocodile.com>

### What is the best car to have?

There are a wide variety of cars on the road today, from the high-cost and high-speed Ferrari to the run-about Fiesta. The choice of car can depend on factors such as cost, colour, parking space required and safety. Until the end of the 1960s fuel efficiency was generally not considered important; petrol was cheap and plentiful. However, an oil crisis developed in the early 1970s, forcing the car industry and petrol companies to think about the possibility of only having access to a limited amount of petrol at high cost. Drivers began to think more about the cost of driving. In the 1980s and beyond, the effect of greenhouse gases, some of which are produced in part by car exhaust fumes, caused people to think more deeply about the pollution produced by vehicle use.

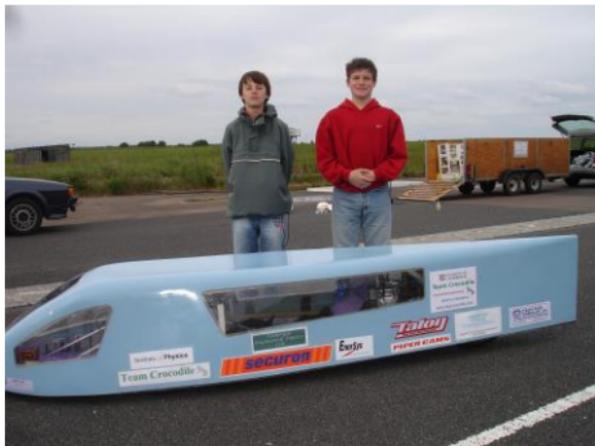
One answer to these problems lies in better fuel efficiency. The modern world cannot function without goods being transported along roads, and many people live a great distance from their place of work. Public transport can help many people, but it cannot solve every transport problem.

Table 1 shows comparisons between a high-speed racing car, a sports car, a standard family car and the Team Crocodile fuel-efficient car. Speed is not always the most important thing to look for when choosing a car; some cars cannot travel very far on the amount of petrol that an average family can afford.

### How can we make a car more fuel-efficient?

To make a car more fuel-efficient we need to understand the scientific factors that affect the fuel-efficiency of the car, and have the technology to put this knowledge to use. The major factors that affect the fuel-efficiency of cars are:

- **Friction:** How much grip is needed to help the engine push the car along? Is there too much grip, slowing the car down? Are the car tyres made out of soft or hard rubber?



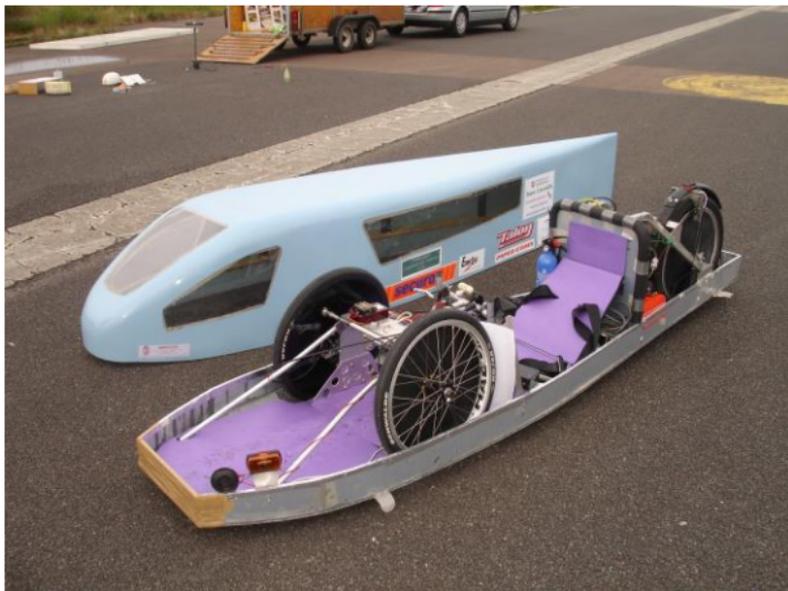
↑ **Figure 1:** Team Crocodile's Fuel-Efficient Car & Drivers

- **Aerodynamics:** What is the best shape for a high-efficiency car? What affects the stability of the car?
- **Weight and Power:** What is the most appropriate engine size? A large engine may give extra power, but is all that extra weight a good thing?
- **Technology:** What are the best materials to use for different parts of the car (e.g. tyres, body shell, axle and bearings)? Why?

Type of Car	Maximum Speed (mph)	Efficiency (mpg)
Formula 1 Racer	185	2
Sports Car	130	35
Family Saloon	90	50
Team Crocodile Fuel-Efficient Car	35	3,894
Fuel Efficient World Record 2005	25	11,254

↑ **Table 1:** Maximum speed and fuel efficiency for different types of car

## The Team Crocodile Fuel-Efficient Car



↑ **Figure 2:** Inside Team Crocodile's fuel-efficient car.

Rik Balsod, a research assistant at the Cavendish Laboratory, instigated the Team Crocodile project in 1996. The aim of the Team Crocodile project was to provide a learning tool to enable students in schools to get hands on engineering experience, share ideas and understand the importance of team work.

The Team Crocodile car was constructed with a great deal of help from the University of Cambridge Engineering Department, where Dr. Alan Organ and his colleagues devise student design projects to develop specific chassis structures and body shell aerodynamics. Their models were tested in wind tunnels and the final design was then constructed by the technical staff. The car chassis is made from 10mm honeycomb aircraft specification material to give a light but strong construction. The body shell is made from fibreglass, which is light and smooth and easily shaped. The tyres are Michelin (20" x 1 $\frac{3}{4}$ ") and the brakes are calliper brakes, similar to those found on bicycles.

## **The Shell Eco-Marathon**

The Shell Eco-Marathon was a competition that was held in the UK for over 30 years until 2010. The challenge of the competition was to build a vehicle powered by an internal combustion engine to carry a passenger as far as possible on one gallon of fuel. It was a world-renowned international competition in which schools, colleges, universities, companies and individuals took part.

In the competition cars were required to drive at an average speed of at least 15 miles per hour for seven laps around Rockingham racetrack, which is a total distance of 10 miles. At the end of the seven laps the amount of fuel used was measured. The fuel-efficiency of the car could then be calculated.

In 1996, our first competition attempt, Team Crocodile achieved 2nd place in the “newcomers” category. The efficiency of the Team Crocodile car was found to be 2,101 miles per gallon, representing an overall position of 9th in the UK, and 22nd in the world. The winning team had over £1,200,000 support from the car industry and achieved an efficiency of 9,472 miles per gallon. In 2002, Team Crocodile were placed 5th in UK, and 6th in the world, having increased their fuel-efficiency to 2,712 miles per gallon (winning team achieved an efficiency of 10,240 miles per gallon). In 2005, the world record was broken by a Japanese team with 11,254 miles per gallon and a budget of £3,200,000.

Our Team Crocodile project is exhibited during National Science Week, Physics at Work and on bespoke school trips. One of our best achievements has been to inspire 97 students into apprenticeships and industrial studies, 37 of which were girls with 23 going on to graduate from university. Of the 60 boys, 43 went on to graduate. Two girls were successful in receiving Masters degrees and two boys their PhDs! The results of our entries in competitions in 2017 will be available at the Physics at Work 2017 Exhibition, and on our website.

Team Crocodile is still very much active, despite the Shell Eco Marathon event being stopped in the UK in 2010. A few of the members of the teams have managed to carry on the tradition so youngsters can still compete – now at a new venue, Mallory Park Racing Circuit.

## 7. Earth Sciences (Dept. Of)

### Bullard Laboratory

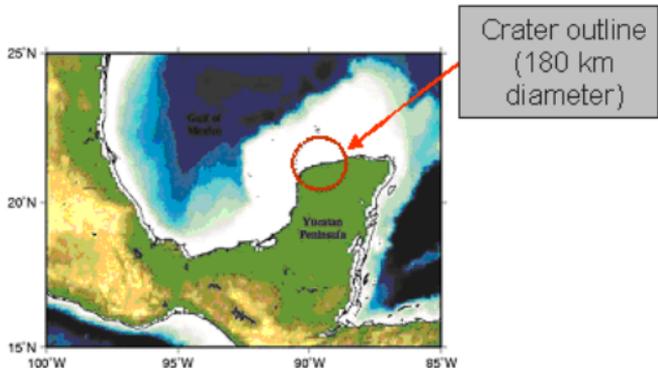


<http://www.esc.cam.ac.uk>

#### Seismics - A look at Global Catastrophe

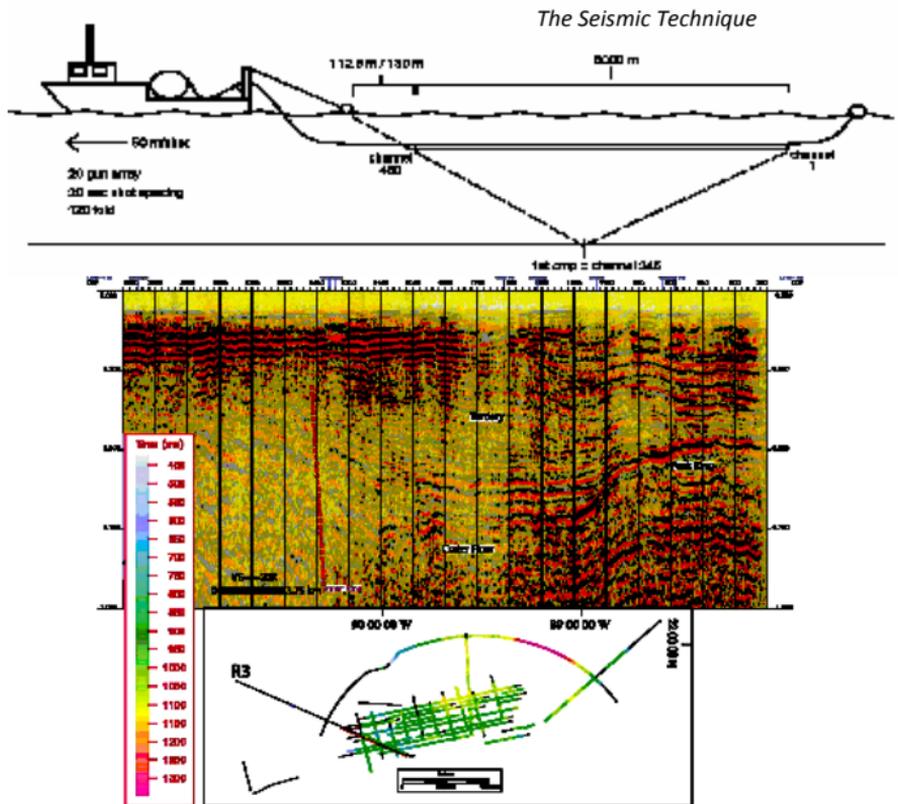
Sixty-five million years ago a 10 km diameter meteor crashed into the Yucatan Peninsula of Mexico leaving a 200 km wide crater. This crater is known as the Chicxulub crater (it is named after the small fishing village that is now at its centre). It is one of only three known impact craters on Earth with diameters larger than 150 km. Seventy percent of the species on the Earth including the dinosaurs went extinct during the time that this impact occurred, and there is strong evidence that the red hot dust thrown up by the impact was responsible – having effectively barbecued anything on the surface of the earth! The area around the impact point is now completely flat under a 1 km layer of limestone, and the crater was first identified by gravity surveys that revealed a strong concentric pattern. More recently seismic studies have been used to investigate the structure of the earth's crust around the crater, with a view to getting a better understanding of the size and direction of the impact and of the disturbances caused.

The University of Cambridge has recently been involved in the largest seismic survey of the crater, involving over a month of seismic shooting and recording with hundreds of



receivers on the seabed and on land. Preliminary results show the exciting sectional views of the crater, which we will be presenting.

As well as showing our hot-off-the-press scientific results, we explain the seismic technique using simple demonstrations of waves, and show how these can be built up into profiles that are virtual cross sections through the earth's crust. The resulting technique is by far the most powerful tool we have for probing the outer layers of the solid earth. As well as yielding unique insights into the earth's history, the entire oil and gas industry is based on the use of seismics to locate and identify reservoirs and track the movement of oil and gas during extraction. The enormous economic importance of the industry makes it a major employer of scientists and technologists, with many exciting and well-paid job opportunities.



## 8. Mathworks

### What does MathWorks do?

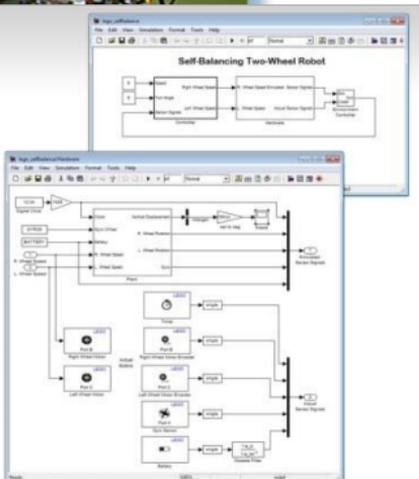
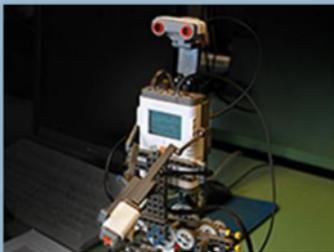
MathWorks is the leading developer of mathematical computing software. Engineers and scientists worldwide rely on its products to accelerate the pace of discovery, innovation, development and learning.

### What are MATLAB® & Simulink® ?

Physicists, scientists and engineers use computers to simulate, visualise, and analyse data from their experiments, and discover patterns and new characteristics in them. MATLAB is the leading environment for performing such scientific and technical computing. They also use graphical tools to build computer models to simulate the behaviour of real world systems. Simulink is

a graphical environment for simulation and Model-Based Design.

MATLAB and Simulink enable fundamental research, the design and development of a wide range of advanced products, including automotive systems, aerospace flight control and avionics, telecommunications and other electronics equipment, machinery for industry, and medical devices. More than 5000 colleges and universities around the world use MATLAB and Simulink for teaching and research in a broad range of technical disciplines.



## **Hardware support for Project Based Learning**

Project-based learning allows students to obtain “hands-on” experience working with both hardware and software. By incorporating industry-standard software tools such as MATLAB and Simulink, teachers can introduce students to the exciting field of technical design and innovation. Furthermore, the students also develop a whole host of skills highly sought by employers in a wide variety of careers. MATLAB and Simulink allow for such project-based learning through built-in support for interfacing with popular low-cost hardware, including Arduino®, LEGO® MINDSTORMS® NXT, and Raspberry Pi® platforms.

### **The Experiment**

Physics provides us with the tools to model “real-world” physical systems. Specifically, this means we can represent a real system through a mathematical model of its component parts. Such models allows us to simulate the system in a variety of different scenarios without actually having to build any of the hardware involved. This has the advantage that different solutions can be tested virtually, saving both time and money by uncovering design flaws and allowing the design to be optimised before building an actual implementation.

The demonstration will introduce physical modelling and computer simulation in order to control a two-wheeled segway-style robot using Simulink and a Lego Mindstorms NXT.

**Name:** Dr Gareth Griffiths

**Position:** Software Quality Engineer

**Educated in:** Elfed High School

**A-levels (or equivalent):** Maths, Physics, Chemistry

**University:** University of York, University of Cambridge

**Qualifications:** MPhys Physics with Astrophysics (York), PhD in Computational Physics (Cambridge)

**My day to day work involves...** working closely with Software Developers to ensure that the code they write is thoroughly tested; for correctness, performance, and compatibility.

**The best thing about my job is...** the combination of teamwork and individual creativity required and the interesting people that I work with

**The thing I like least about my job is...** not having enough time to work on the most exciting projects all the time- and the deadlines!

**Other careers considered:** Pilot, Finance (was a physics teacher)



**Name:** Dr Andrew Powell

**Position:** Software Developer

**Company:** MathWorks

**Educated at:** Corfe Hills School, Dorset

**A-levels (or equivalent):** Maths, Physics, Chemistry

**University:** Imperial College, London & Herford College, University of Oxford

**Qualifications:** MSci, Physics (Imperial), DPhil in Experimental Particle Physics (Oxford)

**My day to day work involves...** working within a small team of fellow Software Developers and Quality Engineers to design and develop robust software features for future versions of MATLAB and Simulink.

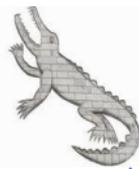
**Other experience or previous professions:** Previously I was a STFC research fellow, based at the University of Oxford, conducting research upon data obtained from the LHC particle-physics experiment at CERN.

**The best thing about my job is...** working with an incredible set of smart, talented people in order to develop software tools that will bring benefits to lots of scientists and engineers all around the world.

**The thing I like least about my job is...** not having enough time to work on all the exciting projects I wish I could work on!

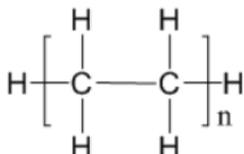
**Other careers considered:** Medicine, Teaching, Finance.



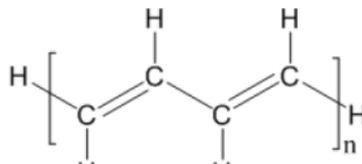


### Making flexible materials that can conduct electricity?

Look around you and you will find a diverse range of things, from cling film to artificial limbs, to electronics made from plastic like materials. Flexibility is one of the key aspects of these materials for they are made from long chain like molecules called polymers. Most of these well-known flexible materials are insulators and especially insulating plastics can be used as a shielding on electric cables to protect you from electric shock.



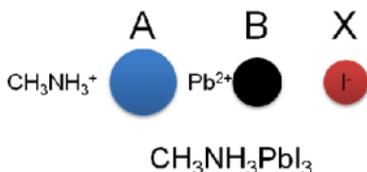
a) Polythene



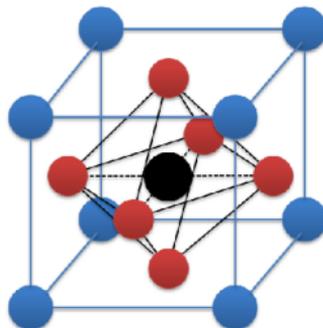
b) Polyacetylene

c) Perovskite

Generic formula:  $\text{ABX}_3$



*Methylammonium-lead-iodide*



**Figure 1:** a) Polythene is used in plastic bags whereas b) Polyacetylene is a metal like compound. c) Shows the crystal structure of perovskite semiconductor.

A newly discovered class of flexible materials - plastics, perovskites have electrical properties similar to silicon (a semiconductor dominating most of the electronics around us). Plastics are long chain like molecules made primarily of Hydrogen and Carbon and perovskites are a class of crystalline materials. To conduct they must have alternating double and single carbon bonds (figures. 1b). Research in the Optoelectronics Group focuses on exploring how these new materials can conduct electricity and how can they be used in LEDs (light emitting diodes), photovoltaics (solar cells) and transistors (electronic switches). We also work on designing controllable functional structures using natural polymers like - DNA as a glue to hold small particles together for new age technological applications in batteries and displays. One interesting thing that we always focus on, is to make all our processes compatible with printing techniques that could enable large scale manufacturing, making the end products economical.

## **Light Emitting Diodes (LEDs)**

LEDs are extremely common and are used as tiny, low power lamps for indicator purposes on electrical appliances. They emit light by a process in which electrical energy is converted into light energy without much heating, unlike the tungsten lamp. However, polymer and perovskite based LEDs are easier to make than conventional inorganic materials (eg. silicon) based LEDs. Such LEDs demonstrate advantages like flexibility, high colour purity and low power consumption. One advantage of using these polymers or perovskites in LEDs compared to the conventional materials is their high brightness that obviates the need of using a backlight.



*Figure 2: A huge (55") curved UHD TV screen*

## **Photovoltaics (PVs)**

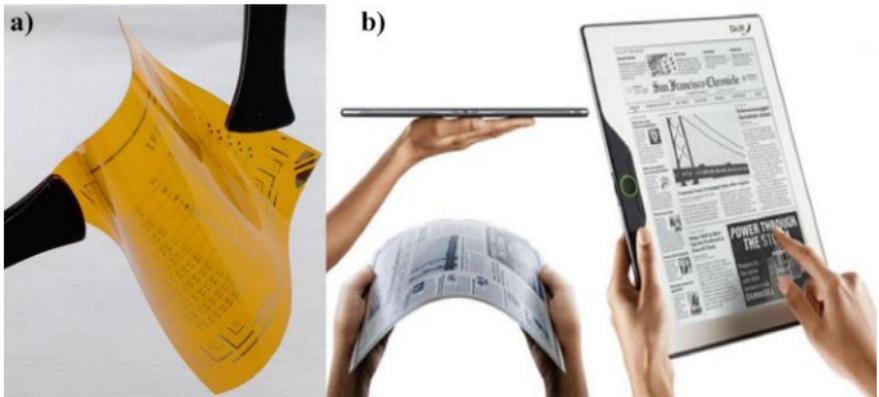
Solar cells (or PVs) are an essential part of our quest to produce clean energy from sunlight. PVs can be found embedded in a range of appliances - calculators, clocks and satellites, where the energy from the sun is used to generate electricity. In an LED, electrical energy is converted into light energy. By running an LED 'backwards', the light energy can be transferred into electrical energy in a solar cell. Light absorbed by the polymer or perovskite material generates positive and negative charges that can be collected at electrodes and the solar cell will then act like a battery. In our group, we also look at exploiting some unique phenomenon found in particular materials that helps in generating double the current than conventional materials from a single incident photon. This two-for-one process is known as 'Singlet Fission'. We use this process to enhance the efficiency of the present day PVs.



**Figure 3:** Flexible and lightweight solar cell based backpack makes it easy to produce electricity in remote areas

## Field-effect Transistors (FETs)

An FET is an electronic switch. When a voltage is applied to one terminal to form a path for charge, it is 'ON' and charges can flow between two other terminals. When the voltage is removed, the path disappears and it is 'OFF'. The FET is the basis of all modern microchips and a computer or a mobile phone has several billion FETs inside processing the information. Using FETs made out of polymers or perovskites, flexible microchips can be produced at very low cost so it has big advantages in high volume applications. Recently, the best polymer and perovskite FETs showed similar speed to FETs made of amorphous silicon and there is a strong possibility to develop new polymers with better performance. Moreover, FETs with intrinsic flexibility and lightweight attributes can be applied to new products such as electronic newspapers (*figure 4*) or "smart skin" covering artificial limbs.



**Figure 4:** a) A flexible transistor that is used in making b) flexible electronic newspaper

Do watch out for flexible electronics coming out in form of a cool gadget. OLED screens are already in use in many mobile phones and flexible screens are expected to be on the market within a year. Maybe one day we will be able to watch TV on a lightweight flexible screens that can be rolled up like a poster when the programme is finished! Also, imagine going camping and carrying a roll of flexible and feather-light solar cells in your backpack that you can unroll and charge up your electronics in a no man's land! Doesn't it sound exciting?!



**Figure 6:** Samsung's flexible mobile phone screen

## Useful websites

Cambridge Display Technologies: [www.cdtltd.co.uk](http://www.cdtltd.co.uk)

Plastic Logic: [www.plasticlogic.com](http://www.plasticlogic.com)

Readius: [www.readius.com](http://www.readius.com)

FlexEnable: [www.flexenable.com](http://www.flexenable.com)

Eight19: [www.eight19.com](http://www.eight19.com)

**Name:** Dr. Aditya Sadhanala

**Position:** Research associate

**Educated in:** Mumbai, India

**A-levels (or equivalent):** International Baccalaureate equivalent with pure Maths, Physics, Biology and Chemistry

**University:** Mumbai, India and Manchester, Cambridge, UK

**Qualifications:** Bachelor of Electronics Engineering, Msc in Nanoelectronics and PhD in Physics

**My day to day work involves...** analysing results from my experiments where I made polymer samples on glass and test them under a special machine built by me, which measures the amount of light absorbed by the polymer material. The interesting thing here is that this machine is inspired by the natural mirage effect which gives you an illusionary effect when observing distant objects!

**The best thing about my job is...** making new things in the lab, gaining knowledge and helping out other people in the group

**The thing I like least about my job is...** it can get a bit busy at times!

**Other careers considered:** Inventor, philosopher, engineer, farmer and cricketer.



**Name:** Darshana Joshi

**Position:** PhD student

**Educated in:** BSc Hons in Physics , M.S.(with research) in Materials Sciences, Ph.D in Physics, University of Cambridge

**A-levels (or equivalent):** Physics, Maths, Chemistry, Computer Sciences, English

**My day to day work involves:** Designing interesting assemblies and patterns of small polymer particles using DNA as an intelligent glue that can emulate naturally existing patterns found in butterfly or beetles wings. I image these structures using optical microscope and analyse data using codes that I write in a programming language called Matlab.

**Other experience/previous profession:** My M.S. course was research-based and like some other members of the Optoelectronics group, I worked on making semiconducting devices. I also teach first and second year undergraduate students and do a lot of public engagement activities both in India and UK.

**The best thing about my job is...** The joy of discovering cool stuff!!

**The thing I like least about my job is...** Having to repeat same experiment hundreds of times before making concrete conclusions can get a bit boring

**Other careers considered:** Science communicator, Educationist, Social worker, UN



**Name:** Arfa Karani

**Position:** PhD Student

**Educated in:** India and UK

**A-levels (or equivalent):** International Baccalaureate with Maths, Physics, Chemistry and Economics

**University:** University College London (UCL), UK

**Qualifications:** First Class Honors in MSci Physics

**My day to day work involves:** Making solar cells, testing them with different machines, analysis data using very interesting 3D softwares. Sometime I also use high resolution electron microscopes to look at 'quantum dots' that are 3nm or smaller in diameter.

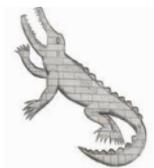
**The best thing about my job is...** Learning new things everyday! Almost everyday I return home knowing something very exciting and new...and everyday is different!

**The thing I like least about my job is...** you don't always get solutions to the problems right away, research can teach you a lot of patience.

**Other activities I enjoy and engage in:** Dancing, stage performances and choreographing, entrepreneurial training.



## 10. Astrophysics Research Group



<http://www.mrao.cam.ac.uk>

### Astrophysics:

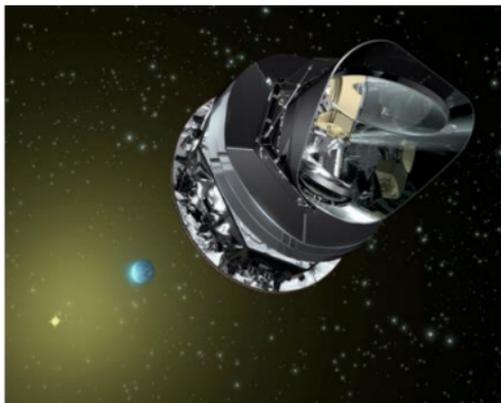
Astrophysics is all about making measurements and predictions about how the Universe fits together. Our research group involves theorists, who use complex mathematics to solve the equations of the Universe, engineers who build telescopes and design experiments to collect data from the Universe and astronomers who study the data we gather and try to see if the theorists were right or wrong!

The Astrophysics group at the Cavendish has historically been involved closely with radio telescopes – telescopes that pick up radio waves from outer space. These waves are naturally generated and don't (necessarily) come from distant civilizations, but they do tell us a lot about the physics in different parts of the Universe.

We are currently involved in several telescope projects. One, the Planck satellite was fired into space in May 2009 and is now sitting at the so-called “L2” point, 1.5 million km from Earth.

Planck's job is to map radiation patterns from when the Universe was very young and hot, when it was only about 300,000 years old.

We are also working on a telescope called “The Square Kilometer Array” or SKA. This will be a huge ground-based radio telescope with over a million square meters of collecting area, making it by far the most sensitive telescope ever built. The SKA will have up to 3,000 dishes, each 15m in diameter. By comparing the signals from different dishes in the array, astronomers are able



↑ **Figure 1:** Artist's impression of the Planck satellite showing the Earth and Sun in the background. Credit: European Space Agency



↑ **Figure 2:** Rendition of what the SKA might look like, with up to 3,000 dishes spread across the desert. Credit: SPDO / Swinburne Astronomy Productions

to build up very detailed maps of the objects in the sky that shine at radio wavelengths.

One of the aims for the SKA is to build up a 3-D map of the positions of a billion (a thousand million) galaxies in the sky. The positions of these objects will span a range of distances from Earth, so, because the radio light from distant objects will have taken time to get to Earth, we will be looking back in time. We can then use our 3-D map to see if the patterns of objects are different for the nearby objects (when the Universe was almost as old as it is now) and distant objects (when the Universe was much younger). This will tell us how the Universe has been changing as it gets older.

We also work on another new telescope called ALMA, which is located in Chile. The 66 dishes of ALMA work at relatively high radio frequencies. ALMA is very good at studying the light from “proto-planetary disks” which are the swirling masses of dust, ice and rock that appear as stars form, and which ultimately lead to the formation of planets.



↑ **Figure 3:** The 66 high-precision dishes of the ALMA array. Credit: ESO/Clem & Adri Bacri-Normier

ALMA will help us to understand the processes of planet formation, which is very important to see how unique our own solar system (and planet Earth) is, and how likely it might be that there are other planets just like our own, and who knows, maybe with intelligent life on them.

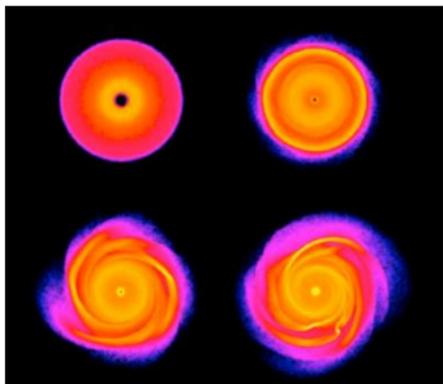
### Some web links:

Chandra X-Ray observatory (lovely pictures):  
<http://chandra.harvard.edu/>

Planck Satellite mission:  
<http://www.sciops.esa.int/index.php?project=PLANCK>

SKA Telescope:

<http://www.skatelescope.org/>



↑ **Figure 4:** Simulation of planets forming out of a swirling disk of matter orbiting a new star. (Credit: Professor T Quinn, University of Washington)

**Name:** Eloy de Lera Acedo

**Position:** Senior Research Associate

**Educated in:** Spain

**A-levels:** Physics, Biology, Mathematics

**University:** University Carlos III of Madrid

**Qualifications:** EngD in Communications technology

**My day to day work involves:** Designing the antennas and electronics for modern telescopes such as the SKA, testing them and creating models for the telescope calibration.

**Other experience/previous professions:** I have always worked on designing instrumentation for astrophysics.

**The best thing about my job is:** I love going to astronomical observatories around the world and seeing my designs working.

**The thing I like least about my job is:** Not being able to spend the whole working day researching new ways to design better telescopes.

**Other careers considered:** Physicist, Aeronautical engineer.



## 11. Rolls-Royce



# Rolls-Royce

<http://www.rolls-royce.com>

### What we do

Rolls-Royce creates power. Better power for a changing world!

Rolls-Royce designs, develops, manufactures and services integrated power systems for use in the air, on land and at sea.

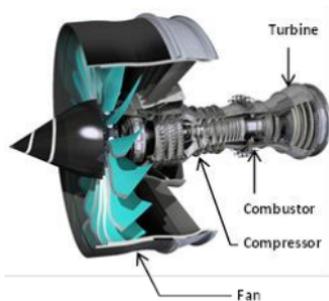
We are one of the world's leading producers of aero engines for large civil aircraft and corporate jets, and are the second largest provider of defence aero engines and services in the world.

For land and sea markets, reciprocating engines and systems from Rolls-Royce are in marine, distributed energy, oil & gas, rail and off-highway vehicle applications. In nuclear, we have a strong instrumentation, product and service capability in both civil power and submarine propulsion.



### Gas turbine technology

- A gas turbine can accelerate air to create thrust (jet engines), drive generators to make electricity, or turn pumps and ship propellers (industrial / marine gas turbines).
- Gas turbines convert the energy from burning fuel via three main elements – a compressor, combustor and turbine.
- Gas turbines have a higher power density than internal combustion engines.





**Rolls-Royce**



### **Fans**

The fan in a gas turbine produces 80 per cent of the engine's thrust, as well as feeding air to the gas turbine core.

The hollow, titanium wide-chord fan blade, pioneered by Rolls-Royce and introduced into airline service in the 1980s, set new standards in aerodynamic efficiency and resistance to foreign object damage. Since that time we have continued to innovate and improve them.

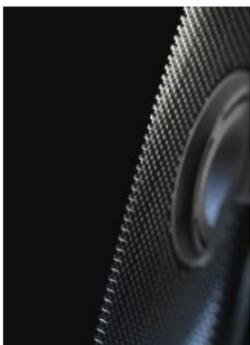
Fan efficiency is an increasingly important contributor to overall improvements in engine efficiencies.



### **Compressors**

The primary purpose of the compressor is to increase the pressure of the air through the gas turbine core. It then delivers this compressed air to the combustion system.

The compressor comprises the fan and alternating stages of rotating blades and static vanes.



### **Combustion**

Fuel and air are mixed and burned within the combustion chamber to convert chemical energy of the fuel into thermal energy within the gas-stream prior to entry into the turbines.

The needs of the system depend greatly on the application (civil or military aerospace, marine or power generation). However there are many common themes of technology that span all sectors.



### **Turbines**

An increasingly detailed understanding of the turbine is necessary to produce more fuel efficient engines.

Turbines blades extract power from the hot, fast gases downstream of the combustor. They spin at around 12,500rpm and live in an environment 200°C hotter than their melting temperature - that's like putting an ice cube inside an oven.



Research and development

£1.2bn

University technology centres

31

Advanced manufacturing centres

7

**Name:** Kris Thomson

**Position:** Engineering Graduate

**Educated in:** University of Glasgow

**A levels:** Maths, Physics, Chemistry, Information Systems

**Qualifications:** MEng Aeronautical Engineering



**Day to day work involves...** I'm on a graduate placement which involves 4 four month placements throughout the company. I'm currently working as a Development Engineer on the Trent 7000 engine project. This involves writing strategies for verifying the different components in the engine work as we expect them to and defining tests for our development engines.

**The best thing about my job is...** I can understand the links between all the different components in an engine, which is really fascinating. The work I am doing is on real projects, so I can see how it makes a difference to helping deliver engines to our customers.

**The thing I like least about my job is...** When my inbox is overflowing with emails, thankfully it doesn't happen too often!

**Other careers considered:** Pilot

**Name:** Marcin Mazur

**Position:** Manufacturing Engineering Graduate

**Educated in:** University of Bath

**A levels:** Maths, Further Maths, Physics, Spanish

**Qualifications:** MSci Maths & Physics



**Day to day work involves...** working in a few different areas of the business. This way I can see what different parts of the company do in terms of manufacturing and gain a better understanding of what to do in the future. Once the programme finishes, I can choose the place that I want to work in out of the ones I worked in or choose somewhere else. Currently, I am on a rotation called Design and Make, where teams are given twelve weeks to solve a problem that can enable Rolls Royce to save money and make them even more profitable than they are already.

**Other experience:** Summer Internship at Rolls Royce in 2014.

**The best thing about my job is...** that the training and inductions provided allow further development after university.

**Name:** Harry Tate

**Position:** Engineering Graduate

**Educated in:** University of Sheffield,

Queen Elizabeth's Grammar School

**A levels:** Maths, Physics, Biology

**Qualifications:** MEng Mechanical Engineering with Industrial Management



**Day to day work involves...** different areas of engineering on a four month rotation, but I am currently working in Producibility. I work with central Engineering and Manufacturing Plants, managing projects to improve component cost, quality and delivery.

**The best thing about my job is...** that I can directly relate the work I deliver to a business benefit, such as a cost reduction or an improvement in delivery rate. Meeting lots of interesting people with both Manufacturing and Design specialisms means I get to develop a breadth of knowledge.

**The thing I like least about my job is...** travelling between sites, so having to carry all of my work stuff with me all of the time!

**Other careers considered:** Vet



Materials Science is an interdisciplinary subject incorporating elements of physics, chemistry, engineering and increasingly even biology. Generally material scientists are interested in two key questions: firstly, why does a material behave the way it does and secondly how can we exploit or change the properties of a material to make it better or cheaper? Our society is highly dependent on advanced materials. These can range from lightweight composites for transport, silicon microchips for computing, complex materials and structures for renewable and efficient energy supply, and materials to support our ageing population. Materials science can be investigated across a variety of length scales and structures right down to the atomic scale – affecting the gross properties of materials.

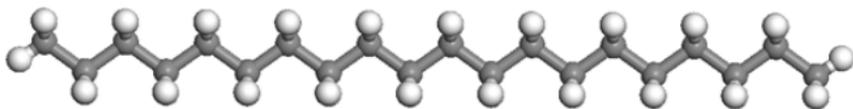
Polymers are more than just plastic bags, packaging or toys. They can be designed to dissolve in water, conduct electricity, or change colour or shape with the application of an electric field or heat. Polymers have always been around; natural polymers include the proteins that make up all living things, cellulose, starches, wood, silk, wool and natural rubber. It wasn't until the early 19<sup>th</sup> Century that the first processed polymers were used. In fact, most synthetic polymers were discovered by accident! The introduction of processed natural rubber and the use of crude oil as a new source of organic compounds kick-started the idea that polymers could be developed for specific purposes with specific properties.

In current times, polymers are used in a huge variety of applications because of their wide range of properties.

### What is a polymer?

Polymers are long molecules consisting of chains or networks of many repeating units. They are formed by chemically bonding together many small molecules called monomers. Polyethylene is perhaps the simplest synthetic polymer and has a structure demonstrated in *Figure 1*. It is what is known as a hydrocarbon with only carbon and hydrogen atoms attached to a carbon backbone. Polyethylene is found in everything from carrier bags, to medical implants, to water pipes (*Figure 2*).

Polymer chains may have a single backbone (which is likely to contain many kinks) or they may be branched. It is also possible for some polymer chains to have bonds between them known as cross-links. These cross-links affect the properties of the polymers as they prevent the chains from being able to move past each other. A simple experiment to demonstrate this is the formation of a cross-linked polymer using PVA glue and borax. Borate ions in the borax form cross-links with the polymer chains in the PVA glue and make what was initially a viscous liquid turn into a gel (*Figure 3*). However, these cross-links are relatively weak and give the material what is called non-Newtonian behaviour. If the polymer is pulled slowly, the bonds are temporarily broken and chains are able to slide over one another, before bonds are reformed. However, if pulled quickly cross links cannot reform and the polymer snaps!



↑ **Figure 1:** Linear chain of poly(ethylene). The monomer unit is  $\text{CH}_2=\text{CH}_2$ . Image courtesy of DoIT PoMS, Department of Materials Science and Metallurgy, University of Cambridge.



**Figure 2:** Polyurethane has a vast array of applications.



↑ **Figure 3:** PVA glue, otherwise known as poly(vinyl alcohol), with borax added to form cross-links. Here, the polymer has been allowed to stretch slowly under its own weight.



↑ **Figure 4:** A shattered polymer squash ball  
– cooling to  $-196^{\circ}\text{C}$  resulted in the rubber ball becoming brittle

Temperature can also have an impact on whether a polymer is brittle (will snap easily) or plastic (can be deformed without breaking). Vacuum forming is a common route for the production of simple plastic objects such as cups and yoghurt pots. When heat is applied to some polymers the molecules gain enough energy to move apart, slide over each other and become untangled. This means they can become soft when heated and formed into all sorts of shapes. Below a certain temperature, known as the glass transition temperature, the polymer chains can no longer slide past each other and they become ‘frozen’ together (*Figure 4*).

**Name:** Dr Jennifer Shepherd

**Position:** Postdoctoral Researcher

**Educated in:** Coombeshead College, Newton Abbot

**A-levels (or equivalent):** Maths, Physics, Chemistry, History (AS Further Maths)

**University:** University of Oxford, University of Cambridge

**Qualifications:** MEng Materials Science, PhD Materials Science

**My day to day work involves...** trying to mimic the materials and structures within the body to better treat injury and disease. Currently my work focuses on the natural polymer collagen, trying to produce and characterise 3 dimensional structures to allow tissue regeneration for applications such as heart repair. The work is extremely varied using chemistry to optimise the materials, physics to image and characterise the structures and biology in order to investigate how human cells respond.

**Other experience or previous professions:** industrial R&D in a small biomaterials company

**The best things about my job are...** working in a field where there is the potential to seriously improve the quality of people’s lives; travelling to exciting countries to talk to scientists from all over the world, having very expensive toys to play with.

**The thing I like least about my job is...** not being able to switch off from it.

**Other careers considered:** Medicine, teaching, industrial R&D.





## 13. BP

### BP at a Glance

BP is one of the world's leading integrated oil and gas companies. We provide fuel for transportation, energy for heat and light, lubricants to keep engines moving and petrochemicals used to make everyday items. Through our operations in more than 70 countries, we find, develop and produce essential sources of energy, turning them into products that people need.



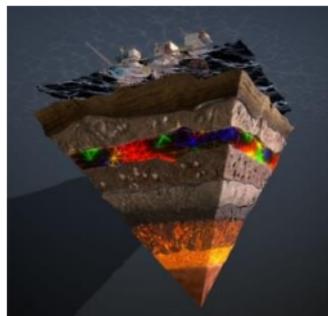
### Physics and Technology

Physics, among other science and technology, underpins everything we do – from discovering and recovering oil and gas, to producing energy efficient and lower-carbon products. For example, knowledge of the Earth's magnetic and gravitational fields is used to detect hydrocarbons, while understanding fluid dynamics is essential to recover such reserves. Understanding and utilizing fundamental physics is an integral part of BP.

## Seismic Imaging

Seismic data provides our most important lens into the subsurface. Using our knowledge of wave propagation, we construct 3D images of the subsurface geological rock structure and explore where hydrocarbon potential may lie. We also use seismic imaging to detect changes in the reservoir rock as oil and gas is produced (4D seismic).

BP has led the industry in seismic technologies as we seek to deliver high quality images from marine environments and on land, in challenging terrains like deserts, forests and the arctic. One such innovation is our Independent Simultaneous Source (ISS®) technology. ISS® employs multiple seismic sources surveying simultaneously, making large-scale 3D surveys faster and lower cost, allowing improved data quality and lower safety and environmental risk.



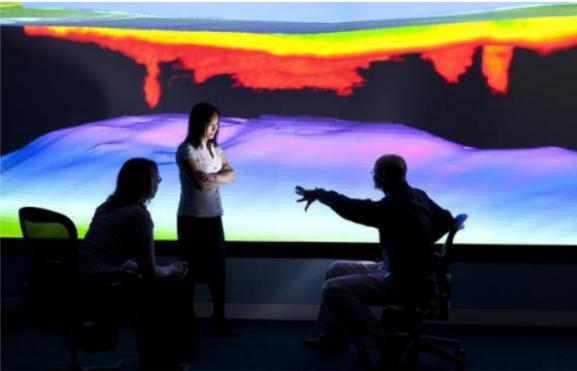
*Figure 1: An image of the earth is built through seismic imaging*



*Figure 2: Acquisition of seismic data on land and sea*

This technology requires excess ‘noise’ to be removed in data processing, before 3D images can be created. This processing is performed in BP’s new Center for High Performance Computing, our worldwide hub for processing and managing huge amounts of geologic and seismic data. Our supercomputer is the world’s largest for commercial research, with a processing power of 3.8 petaflops, which is almost 4,000 trillion calculations per second.

Seismic imaging is just one example of the importance of physics to the energy industry. There are numerous other examples such as using petrophysics to measure rock properties, reservoir modelling to build knowledge of hydrocarbon pools and fluid dynamics to move complex fluids along pipelines into refineries.



*Figure 3: 3D seismic images are visualised and used to find oil and gas reserves*

**Name:** Dr Karen Lythgoe

**Position:** Geophysicist

**Educated in:** Mearns Castle High School, Glasgow

**A-levels:** Scottish Advanced Highers in Maths, Chemistry and Geography

**University:** University of Leeds (MSci), University of Cambridge (PhD)

**Qualifications:** Master of Geophysics (MSci), PhD

**My day to day work involves:** Using seismic data to image the geology below Earth's surface. I manipulate the seismic from raw data collected in the field, to a final geological image. This involves working with large datasets and using/developing code. I also analyse seismic data to find locations of new oil and gas reservoirs.

**Other experience/previous professions:** My PhD investigated Earth's inner core using seismic waves from earthquakes.

**The best thing about my job is:** Exploring the Earth by imaging parts of the world that have never been seen.

**The thing I like least about my job is:** Being in front of a computer for most of the day.

**Other careers considered:** Medicine



**Name:** Elliot Taylor

**Position:** Subsea Project Engineer

**Educated in:** Imperial College London, with Masters completed at The University of Queensland.

**International Baccalaureate Higher:** Maths, Physics, Economics.

**Standard:** English, Spanish, English

**Qualifications:** MEng Civil Engineering

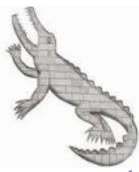
**My day to day work involves...** Management of Subsea contractors through meetings, individual discussions, reviewing reports and performance/schedule tracking. My main scope is the management of a pipeline landfall. Pipelines are installed using large ships, some more than 50,000 tonnes and costing \$1million per day, but in as you get closer to the shore, and the water becomes shallower, the large ships have to handover to smaller ones. Near the beach the ship is fixed in place with multiple anchors and a wire is passed to a 600 tonne winch anchored to the sand, and the steel pipeline is pulled to shore. My role is coordinating all the different teams involved, making sure the operation is planned correctly, and delivered safely and on time.

**Other experience or previous professions:** Rapid response design engineer for water pipelines destroyed by landslides and rivers.

**The best thing about my job is...** It's complicated and engaging. No day is ever the same!

**The thing I like least about my job is...** Things will go wrong, no matter how hard you try. But I tend to blame myself anyway.





## **14. Fracture and Shock Physics Group**

<http://www-smf.phy.cam.ac.uk>

Part of the research within the SMF group in the Cavendish Laboratory is about understanding the dynamic properties of materials. Our research includes studying:

- *Physical phenomena:* How do materials age? What properties affect their strength?
- *Chemical phenomena:* How can energy be stored and released?
- *How materials break and fail:* How do different materials fail? How do they behave in impacts?

We have a world-wide reputation for studying the dynamic mechanical properties of materials. Today, we will show you some of the techniques we use and have developed to study the properties of materials in extreme conditions.

### **Our aims**

We believe that the best way to increase our knowledge of the properties of materials is through a combination of experimental work and computer simulations and models. Our experiments are used in two ways:

- Simple experiments to help develop new models;
- More complex experiments to test the predictions of existing models;

We actively participate in industrial and academic research, and our work takes us all over the world.

### **Stress and strain**

We can describe the effect a force has on an object in two ways: stress – the average force felt by the object – and strain – how much that force changes the size of the object. But when a force acts on a material, it isn't just the size of the force that's important, but the speed with which it's applied: we call this phenomenon 'rate dependency.' A traditional example of this is silly putty: pull it slowly, and it stretches out to a thin fibre; pull it quickly and it snaps. When left for days it can even drip and flow through holes.

In reality, it means that the way a material behaves when deformed slowly can differ greatly from its behaviour at a fast rate of deformation. Within our group, we have equipment that can deform materials at rates from a few millimetres per hour to thousands of metres per second and every rate in between!

### **Stress concentration: flaws and failure**

Materials fail when the stress in them exceeds their strength: usually this occurs because the stress has been 'localised' in one area by a flaw in the material. In part, the strength of a material depends on how a force is applied to it.

Understanding how stress builds up in a material – be it a single sheet of paper or an entire bridge – is vital if we want to predict how it will behave in everyday life. Today, we'll look at ways we can see stress in materials, and how flawless materials can be surprisingly strong.

### **Energetic phenomena**

The rate at which energy is delivered into an object has a dramatic effect on its behaviour. What if instead of slowly applying current to a light bulb, we put all the energy through the filament in a few nanoseconds?

Explosives generate a lot of gas and heat, and this can be used to do work. For example, a cannon uses the gas produced by burning gunpowder to force the cannon ball up the bore. Gunpowder on its own doesn't do anything spectacular – its power comes when it is confined. We will demonstrate this by first burning gunpowder on the desk and then confined in a can by a cork. Strictly speaking, gunpowder is a propellant, not an explosive. The velocity at which a burning reaction moves in a propellant is typically around 800 m/s. Explosives detonate: The reaction moves through an explosive at thousands of metres per second. The fastest reaction you'll see today is the explosion of a length of shock tubing – an explosive-filled plastic tube used to set off large explosions in quarries and mines.

### **High-speed photography**

All these processes, like the failure of a material or detonation of an explosive, happen much faster than the eye can see. A normal television camera shows still pictures at the rate of 25 frames per second – our brain 'blurs' these

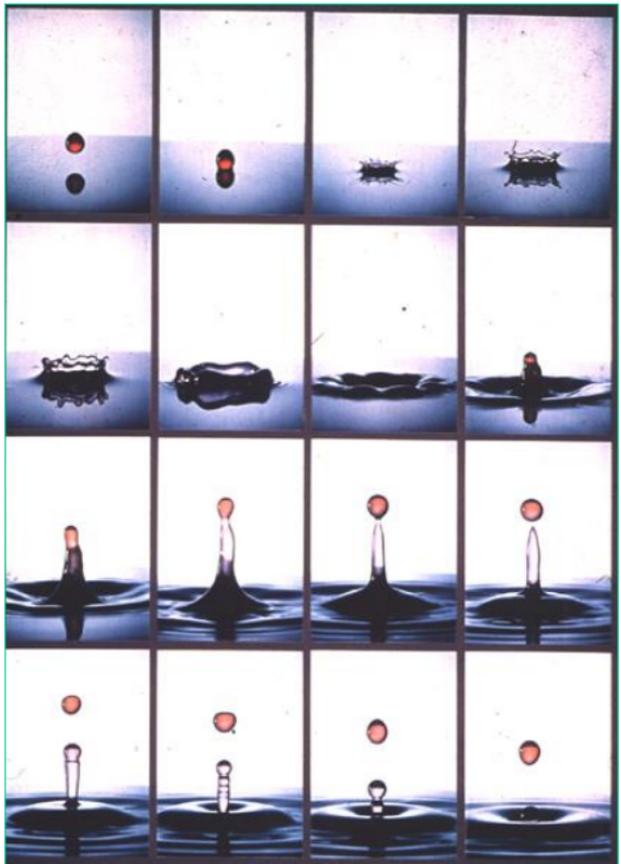
images together to create the illusion of motion. In the laboratory, we employ cameras that can capture between 1000 and 100,000,000 frames per second to record ultra-fast phenomena. The first use of high-speed photography was to settle a bet: does a galloping horse ever have all four of its feet off the ground?

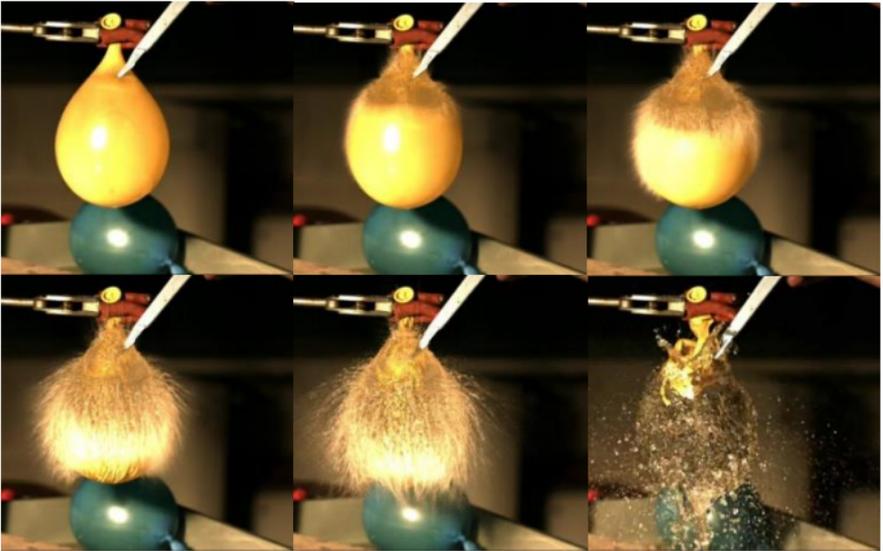
Today, we will use our high-speed video camera to show some of the surprising things that happen faster than the eye can see.

In the first frame the drop nears the surface. In the second, the impact has occurred and the drop has pushed the liquid aside producing a crown-shaped splash. In the following frames, the liquid rebounds and throws up a column or jet. Sitting on top of the column is the original drop of coloured water.

**Figure 1:** →

*A sequence showing a drop of red-dyed water falling into a pool of blue-dyed water.*

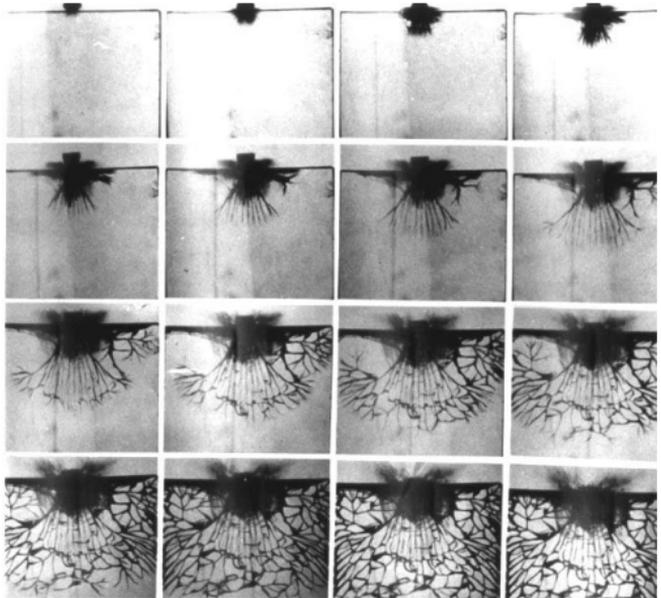




↑ **Figure 2:** A sequence of images from a high-speed video recording of a water balloon being burst. Notice how the skin of the balloon ‘unwraps’ leaving a ball of water that subsequently falls away.

**Figure 3:** →

The propagation of cracks in a 50 x 50 x 6.2mm sheet of toughened windscreen glass, after impact with a lead airgun pellet at the top. The time between frames is two millionths of a second.



### Curious Physics – Problem Solving

Expect the unexpected, predict the unpredictable. Physics is the science which helps us to understand everything around us, from the tiniest particles through to the infinite (or not) Universe.

Fundamentally, physicists are problem solvers! When presented with a puzzle, we use the skills we have practised to solve a huge variety of problems, from building more efficient solar panels to solve the world's energy crisis, to the latest mobile devices that use up some of that energy. Being an expert problem solver allows us to approach curious problems and explain the unexpected or predict the unpredictable.

Let's give it a go. Look at this table and buckets in the picture below, is this table defying Newton's Laws of Physics? A good way to start looking at this problem is to:

**Look at the problem and find the goal of the problem:** how is the table being supported and how much mass must be in each bucket?

**Draw a diagram of the situation:** in this case, you will want to draw the forces acting on each object; the table top and each of the buckets. And don't forget to label ALL the forces on your diagram!

**Identify the relevant physics concepts and useful equations, and what we can neglect:**

Is the table in equilibrium? Do Newton's laws of gravity apply? Are the strings extending significantly? Do we need to consider Hooke's Law?

**Work out the solution:**

work logically through the problem writing down each step, otherwise it is very easy to make mistakes. Even the most experienced physicists do!

**Now check your working:**

do the units match? Does the amount of mass you need make sense physically - would you expect to need 1000 kg for example?

**Correct?** Sit back and enjoy the satisfaction of having solved a curious problem!

There are many more curious problems in physics, such as the Mould Effect (<https://youtu.be/YZ1-4DVLSZ0>) or the Magnus Effect (<https://youtu.be/2OSrvzNW9FE>). Being able to explain these questions by applying your physics knowledge isn't always easy. However, it becomes easier



the more problems you solve, and to become an expert problem solver takes practice. It is a bit like training for a marathon, do a little bit of training every day and you will succeed. Do a little bit of problem solving every day, and you will be able to explain these amazing effects!

isaac Physics. You work it out.

Questions Concepts

MENU Mastering Physics by Solving Problems: from School to University! Q

**LEARN**

- Try our questions...
- Isaac books, exam help & uni
- Workshops

**TEACH**

- Set assignments & view marks
- Teach with Isaac
- CPD Events

**Prize Draw**

Complete our prize draw board for a chance to win a book or DVD

[More Info](#)

**Isaac Mentor Scheme**

Join an Isaac group and work with one of Isaac's directors for weekly mentoring.

[More Info](#)

**Senior Physics Challenge**

Complete questions to earn a place on a Summer School at Cambridge University

[More Info](#)

isaac

About Us Why Physics? Extraordinary Problems  
Contact Us Biographies Challenge of the Month  
Privacy Policy Tutorial Publications

Get Social

A Department for Education project at the University of Cambridge

All materials on this site are licensed under the Creative Commons license, unless stated otherwise

Isaacphysics.org is here to help! We have over 1000 FREE physics problems of varying difficulties to take you from your GCSE all the way through to university. Working on these problems will help you on your journey to

mastering physics and problem solving. Work through our standard problems first and then have a go at our extraordinary problems on rainbows, tennis or chain fountains.

Remember that as with any training, some days will be harder than others, it is OK (actually encouraged) to get the answer wrong the first time round. All physicists do it, making mistakes is how big discoveries are made and Nobel prizes won. The more you put into physics, the more surprises and rewards it will give in return.

Physics is real, relevant and remarkable!

**Try a question!** (<https://goo.gl/f3NL38>)

Follow the link to have Isaac check your answer for you.

### **Misbehaving student**

Despite the teacher's instructions, a misbehaving student sits on a table instead of a chair. The table is rectangular and horizontal, with four vertical legs. The student had a mass of 50.0 kg. A table leg will break if it experiences a force of greater than 150 N (assume that the student's weight is distributed evenly over each leg). Calculate the force on each leg, to 3 significant figures, and determine whether the legs will break.

## 16. Biological and Soft Systems Research Sector



<http://www.bss.phy.cam.ac.uk>

### What is Biological Physics?

Biology is the science describing how life is built up of complex molecules, such as DNA or proteins, that make part of the cells constituting our body. Many famous physicists who are known for their achievements in traditional physics (like Erwin Schrödinger or Niels Bohr), and also natural scientists such as Darwin, have contributed profoundly to our understanding of life. Some have done fundamental experimental work in areas such as molecular structure and dynamics, photosynthesis, or cell membranes. Others have applied their mathematical skills to develop theories for neural networks, electron transfer and phenomena such as the heart's rhythm. Others have found that their skill as instrumentalists can change medicine, through such advances as computed tomography and magnetic resonance imaging.

Despite these many contributions, physics and biology are still considered by most to be two different subjects. Physics is a discipline that is best defined by its approach: accurate measurements and coherent models to understand observations. Physics itself has two souls: on one hand a “reductionist” drive towards fundamental laws, which gave us Newtonian mechanics, optics, electricity and magnetism, and more recently quantum and particle physics; on the other hand the search for “universal” mechanisms, whereby some simple and system-specific rules give rise to macroscopic phenomena that are not present in the rules themselves. An example of the latter is a phase transition like boiling of water: this phenomenon is just “not there” if you look at the interaction forces between water molecules; other examples are traffic jams or people in crowds finding it hard to move about – these things happen but they are not coded in the rules that drivers and pedestrians give themselves. These systems are often called “complex systems”.

In biology, the rules are well known: molecules obey chemistry. But how these molecules and their reactions come together is phenomenally complex, even within a single cell, and we can make progress by developing the concepts that have been successful in other “complex systems”. It is here that physics and

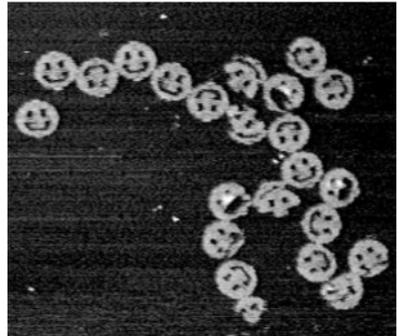
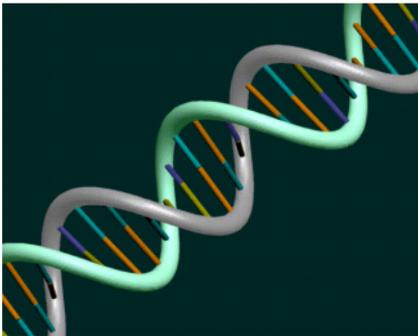
biology currently have a really significant overlap, and important breakthroughs will be possible only by combining a deep knowledge of both areas. This approach is what we, in physics, call biological physics.

### **DNA – a carrier of life and versatile building material for new applications**

The double helix of DNA was discovered here in the Cavendish by Watson and Crick. It is one of the greatest discoveries of the 20th century and led to the understanding we have of genes and how they work. But how are genes actually controlled? Is DNA always a double helix? And how does it all fit inside every human cell? There are 2 meters of it in each cell!

DNA can be used for much more than just biology. We can make new materials out of it, and make complicated three-dimensional shapes - a kind of DNA origami. We can use it to make tiny motors, and boxes that open and shut with a key. And maybe we can make computers out of it as well; a true biological computer.

In BSS we study the way DNA is arranged and moves within cell nuclei, and also use it to build “smart” nanomaterials, from molecular sensors to tiny DNA-origami nanopores that facilitate diffusion through cell membranes.



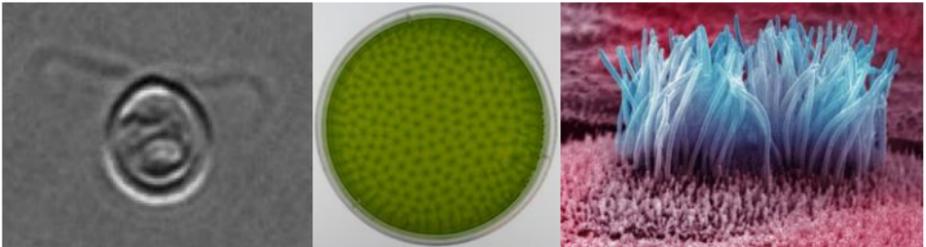
↑ **Figure 1:** DNA origami of viruses made by Paul W.K. Rothemund from a harmless virus-DNA. He “pinched” it into shape with “staples” made from much shorter DNA strands (ref.: P.W.K. Rothemund, *Nature*, Vol 440|16 March 2006|doi:10.1038/nature04586).

### **Beating cilia and swimming microorganisms**

Many microorganisms have evolved to swim and find nutrients. Microalgae, such as phytoplankton in the ocean, swim by beating cilia. Cilia are microscopic

filaments actuated by molecular motors (akin to those in muscle fibres). Cilia are also present in the human body, where they are involved in the transport of fluids, such as beating in unison to clear mucus from our lungs. The fluid environment of cilia is very different from the one we experience, e.g. in the swimming pool. On the scale of a cell, water is like treacle; viscous forces dominate over inertia, so reversible swimming strokes are no use (they land you where you started). Ciliated cells have evolved peculiar beating styles to efficiently propel through ‘treacly’ fluid, or pump it past them.

In the Cavendish Laboratory we study the experimental and theoretical biological physics of ciliary movement; from single cells to populations of swimming microalgae, and up to the tissues we have in our airways. Our research is inspired by current problems in medicine (diseases due to ciliary malfunction) and biotechnology (growing algae for carbon-fixing products and energy).



**↑ Figure 2:** The swimming microalga *Dunaliella* moves by beating two cilia. The cell is also bottom-heavy, so its swimming is biased in flows by a combination of gravitational and viscous torques (gyrotaxis). Gyrotaxis gives rise to the beautiful patterns shown on the right (a top view of a Petri dish). It also causes the peculiar behaviour of suspensions of algae in pipes, which has relevance to culturing algae industrially in photobioreactors, where algae are grown in transparent pipes. (M. D. Haw & O. A. Croze, *Physics World* 25 39-43 (2012) <http://iopscience.iop.org/pwa/full/pwa-pdf/25/02/phwv25i02a37.pdf>). On the right is a touched-up image (from Boots website) of cilia in the lungs; these filaments beat at about 10Hz, and maintain a flow of mucus out of the lungs, serving as a barrier against bacteria and dust.

### **“Imaging” oxygen levels in diseased tissue**

Our cells need oxygen to live and fulfil their functions. Oxygen is constantly supplied by our blood stream to both healthy and unhealthy cells. “Diseased” cells, such as those that are part of tumours, do not consume oxygen in the same way as healthy ones, or simply don’t benefit from the same efficient

delivery. As a result, anomalous oxygen concentrations are found in tumours. Measuring oxygen levels in a non-invasive way is a very useful test to assess the stage of development of the disease and design more effective treatments for patients.

Using imaging techniques based on infrared light and nanoscopic probes, we develop imaging techniques in BSS to “see” oxygen concentrations within living tissue, without the need of invasive surgical procedures (<http://bohndiek.bss.phy.cam.ac.uk/>).



## 17. Computational Radiotherapy

<http://www.voxtox.org>

<http://www.accelrt.org>

Researchers from the High Energy Physics group at the Cavendish are working with engineers, radiotherapy physicists, radiographers and doctors in the University and in Addenbrooke's Hospital to improve ways of treating cancers with radiotherapy.

### Radiotherapy

Radiotherapy refers to the use of ionising radiation to treat disease, particularly cancer. X-rays were discovered in 1895, and the first treatment of cancer with X-rays was performed in 1896. Since then the technology has changed considerably!

The term 'radio' used here is derived from the Latin 'radius' meaning a 'ray' or 'spoke'.

Today's radiotherapy uses high energy X-rays to destroy cancer cells. We have effective methods for delivering the radiotherapy to the target in order to kill the cancer cells. Side effects occur because some normal tissue always lies next to, or even within the edge of, the tumour. Better targeting will reduce side effects and make life better for patients.

Radiotherapy is becoming more and more effective as treatment systems develop in accuracy, hand-in-hand with developments in hardware and computing. Key goals of our research are to help better targeting of cancerous tumours and delivery of the right dose, reduction of side effects (toxicity), and the production of software to help do this.

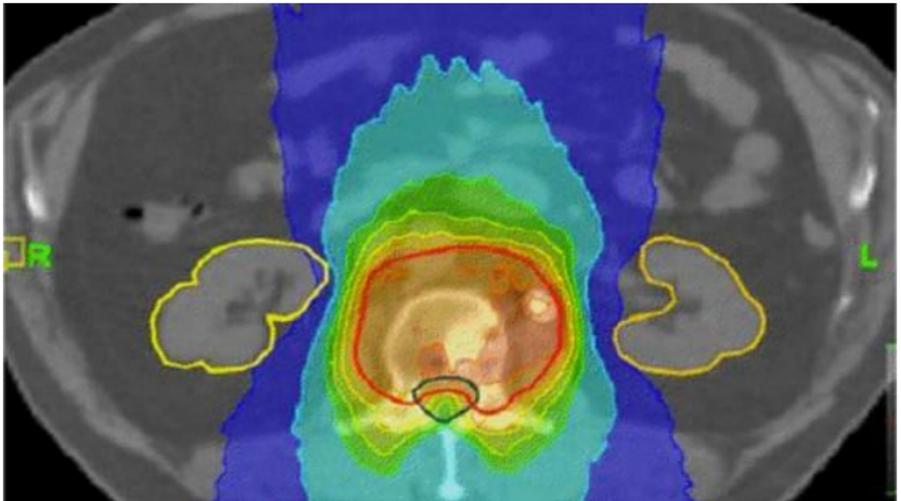
### Radiotherapy treatment

Three advanced approaches are being used which are generating enormous amounts of images and other data. This needs increasingly sophisticated handling so that it can be effectively labelled, stored and retrieved in a reliable and straightforward way. In planning the treatment, diagnostic images of the patient are combined with planning images to set the target areas for the radiotherapy beams. Each day, the patient is imaged in the treatment position

and any corrections made before treatment – a process known as image-guided radiotherapy (IGRT). Treatment is delivered with Intensity Modulated Radiotherapy (IMRT), a technique to treat complex shapes, based on sophisticated computation. The TomoTherapy machine elegantly combines IGRT and IMRT in an integrated treatment solution.



↑ **Figure 1:** A TomoTherapy unit in Cambridge, at Addenbrooke's Hospital. This combines IMRT and IGRT approaches. (Credit: N.Burnet)

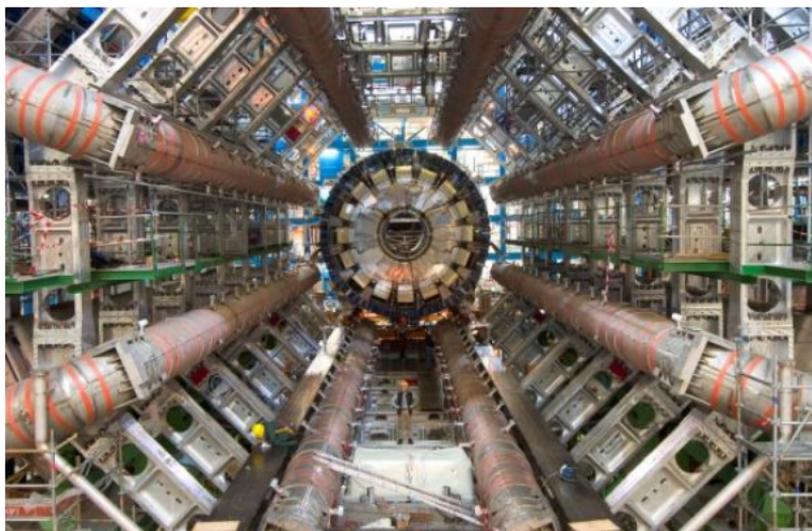


↑ **Figure 2:** Image-guided intensity modulated RT plan for a patient with a spinal tumour. (Credit: N.Burnet)

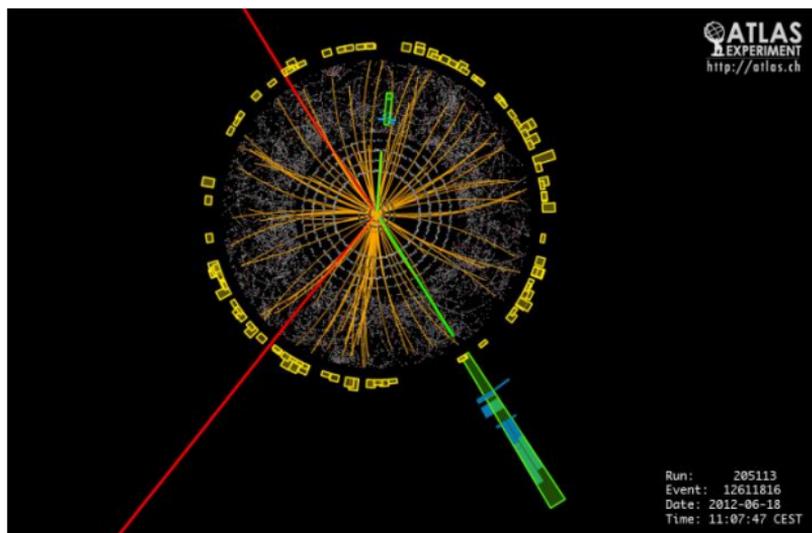
## **What's the link between high energy physics and radiotherapy?**

The connection in our collaborations is through the computational side rather than the particle beam side. The Cavendish HEP group are contributing to the Large Hadron Collider experiments at CERN. Incredible quantities of data are generated from these experiments, generally as images of the particle collisions. So categorising and storing large volumes of data, often images, which require batch processing, is something in which HEP people have a lot of experience. Advanced radiotherapy systems are also generating comparatively large quantities of image and other data which have to be categorised and stored, as well as processed.

We want to help radiotherapy specialists get easier access to the data without seeing all the stages of processing: in other words to make it as transparent as possible to the user. Data are therefore classified hierarchically and catalogued in a database. The use of metadata will allow relevant files to be selected for processing without human intervention. The user simply specifies the dataset in order to run the processing algorithm on all the relevant scans. A single pass through the data will require around 80,000 runs of the algorithm, presenting a problem of scale. Manual logging of the data flows, storage, and processing steps is clearly impractical, and we automate these tasks. The HEP group has extensive experience with distributed processing of large datasets, routinely running thousands of jobs on grid systems worldwide. The Ganga job processing framework [<http://www.gridpp.ac.uk>] was partly developed in Cambridge to automate large job submission runs of this type.



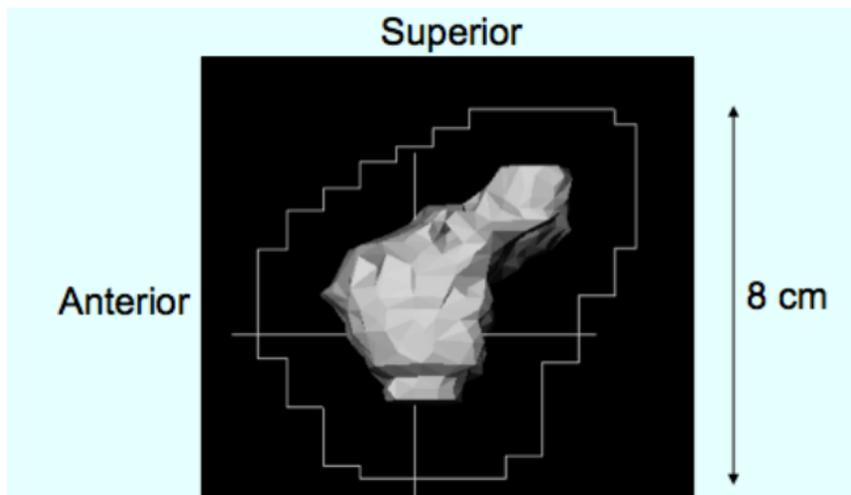
↑ **Figure 3:** the ATLAS detector, at the Large Hadron Collider, CERN. (credit: CERN)



↑ **Figure 4:** Example of an image of a candidate event (possibly Higgs) from the ATLAS experiment. Vast numbers of images of particle collisions are captured and stored. (credit: CERN)

## What about engineering?

It's not all that easy to see how the internal organs move, and imaging them would help us to improve the radiotherapy. Engineers specialising in the modelling of materials and their properties are applying their techniques to modelling organs in the body. When a patient is having radiotherapy, they often have a number of sessions, called fractions, on different days. The cancer specialists prepare a radiotherapy dose plan based on the diagnostic images of the patient. But between fractions, the patient's organs may move. This could mean the radiotherapy will affect non-cancerous tissue. IGRT (image-guided radiotherapy) can track the position of the target before each treatment, ensuring the dose is delivered accurately. Better imaging of normal organs will improve this.



↑ **Figure 5:** Biomechanical model of a prostate (and seminal vesicles) ready to receive radiotherapy (credit: Y.Rimmer and A.Hoole)

## Exhibits

- Planning game: try your hand at creating a radiotherapy treatment plan. Starting from an image of a tumour, try to outline where it is and plan radiotherapy treatment.
- A body shell: this is used to position some patients for radiotherapy treatment.

- Images game: how many images can you match to the correct description?
- A tungsten target from a radiotherapy machine (one of the TomoTherapy units), showing damage to this extremely tough material. This is the result of the electron beam fired at it to generate the high energy X-ray beam.

## Links

HEP schools outreach pages:

<http://www.hep.phy.cam.ac.uk/outreach/index.php>

Physics in medicine pages:

<http://www.insidestory.iop.org/>

## 18. British Antarctic Survey (BAS)

<http://www.antarctica.ac.uk>

### Ozone Measurements in the Antarctic

Ozone is a gas consisting of three oxygen atoms and is formed by the action of sunlight on normal oxygen. When ozone is found near the surface of the earth (such as in smogs formed from car exhausts) it is a noxious substance. Much higher in the atmosphere, the ozone layer protects us from the harmful effects of ultra-violet radiation.

BAS scientists discovered the Antarctic ozone hole over twenty-five years ago and continue to study its annual formation and disappearance. The “Hole” varies in size and duration from year to year, depending on the “weather” in the upper atmosphere. The 2017 hole will be nearing its deepest as Physics at Work takes place – what will we see? Some ozone depletion is seen over the Arctic during the spring, and whilst it can be severe, as it was this year, no major ozone hole has so far formed there. The physics behind the instrument that measures ozone will be explained and you will discover why it is normally only the Antarctic ozone layer that develops a large hole each spring.

Although the amount of ozone depleting gasses in the atmosphere is now declining, we think that it will be another decade before we can say for sure that the ozone layer is beginning to recover.

### Some topics to think about before coming to the exhibition:

1. Differences between the Antarctic and Arctic.
2. Many environmental changes will take place over tens of years, but the measuring instruments may only operate over a few years. How can we tell if or when there has been a significant change in what we are measuring?



↑ **Figure 1:** BAS scientist Jon Shanklin makes an ozone measurement at Halley station.



↑ *Figure 2: Emperor penguins on the sea ice not far from Halley station.*



↑ *Figure 3: The aurora australis (southern lights) above Halley station.*

**Name:** Mr Steven Colwell

**Position:** Meteorologist

**Company:** British Antarctic Survey

**Educated in:** Cannon Slade School, Bolton

**A-levels (or equivalent):** Maths, Physics, Chemistry

**University:** Coventry

**Qualifications:** BSc in Physical Science

**My day to day work involves...** answering questions about the meteorological data that we hold. Building and testing meteorological equipment and then installing it in Antarctica. Travelling to conferences in foreign countries and visiting schools to promote what BAS does in Antarctica.

**The best thing about my job is...** trips to Antarctica.

**The thing I like least about my job is...** dealing with paperwork.



**Name:** Rosey Grant

**Position:** Meteorologist

**Company:** British Antarctic Survey

**Educated in:** Cranbrook School, Kent

**A-levels (or equivalent):** Art, English Literature, Maths, Physics

**University:** University of Bath, University of Leeds

**Qualifications:** MPhys, PhD in atmospheric physics

**My day to day work involves...** I spend the Antarctic summertime in Antarctica and the British summertime in Britain. While in Antarctica I collect and monitor long term meteorological data. I also assist with flying operations by taking weather observations. When I am back in Cambridge my time is spent preparing for the next season and training up the new meteorologists ready for Antarctica.

**Other experience or previous professions:** Fieldwork in UK, Europe, America and Arctic.

**The best thing about my job is...** spending time in Antarctica and learning more about Antarctic meteorology.

**The thing I like least about my job is...** packing, unpacking, packing, unpacking, packing....

**Other careers considered:** Motorsport engineer



**Name:** Jonathan Shanklin

**Position:** Emeritus Fellow

**Company:** British Antarctic Survey

**Educated at:** King's School, Chester

**A-levels (or equivalent):** Maths, Physics, Chemistry, General Studies

**University:** Magdalene College, Cambridge

**Qualifications:** MA (Natural Sciences), PGCE in Physics

**My day to day work involves...** I am one of the scientists who discovered the Antarctic ozone hole. I was responsible for the weather and ozone measurements in the British Antarctic Territory, which included testing equipment, processing data, writing reports, attending scientific meetings and visiting Antarctica. I continue to monitor the climate and ozone data from Antarctica.

**Other experience or previous professions:** Geology field work, optical research

**The best thing about my job was...** going to Antarctica.

**The thing I liked least about my job was...** dealing with paperwork, but now that I'm retired I can avoid most of it.

**Other careers considered:** Astronomer



**Name:** Tim Barnes

**Position:** Data Manager

**Company:** British Antarctic Survey

**Educated in:** Hills Road Sixth Form College, Cambridge

**A-levels (or equivalent):** Maths, Physics, General Studies, Further Maths (AS-Level)

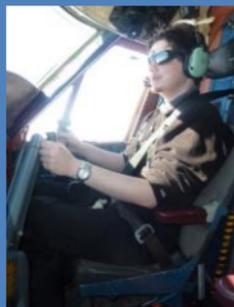
**University:** University of Reading, Anglia Ruskin University

**Qualifications:** BSc (hons) Physics and Meteorology, PGDip Computer Science

**My day to day work involves...** ensuring that data is transferred from the Antarctic stations to our HQ in Cambridge, and then making that data available to the scientists and their collaborators. Additionally, I set up computer systems for installation on the stations, as well as monitor them remotely from the UK.

**Other experience or previous professions:** Retail

**The best thing about my job is...** Trips to the Antarctic.



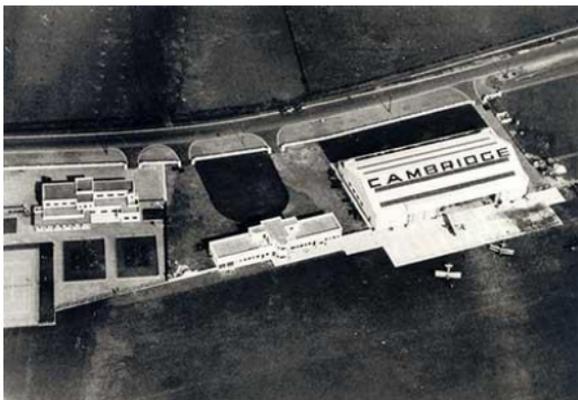
## 19. Marshall Aerospace and Defence Group

<http://www.marshallgroup.co.uk/>

<http://www.marshallaerospace.com/>

### Short History Lesson and What Marshall ADG Does

Marshall of Cambridge was first established in 1909 by David Gregory Marshall, as a chauffeur drive company in a small lock-up garage in Brunswick Gardens, Cambridge. After the First World War Marshall became a dealership for Austin car's sales and it was towards the end of the 1920's that the son



of David Gregory Marshall (Sir Arthur Marshall) graduated from Jesus College, Cambridge.

Sir Arthur learned to fly in 1928, and shortly thereafter created an airstrip near his family's Cambridge home, which by 1929 had turned into a full-fledged airfield. Six years later in 1937, Sir Arthur and his father, David, bought the land where the present Cambridge Airport now stands and started Marshall Aerospace. During World War II, Marshall's played a key role in training over 20,000 air crew.

Under Sir Arthur's guidance, the firm became the UK's largest aircraft repairer, fixing or converting 5,000 planes during the war. Over the years, such major airplane manufacturers as De Havilland, Bristol, Vickers and English Electric have entrusted Marshall's with the servicing of their aircraft.

Marshall's company built, under subcontract, the famous droop nose for Concorde during the 1960's. During the 1980's Marshall's ties with the RAF



were solidified by the conversion of C-130 Hercules to perform air to air refuelling in response to the Falklands Conflict, this vital modification was designed and installed on the aircraft within a fortnight.

The C130 aircraft is widely used by many air forces across the world and even civilian companies in every conceivable environment. It is widely recognised as the work horse of military forces, finding use in both supply and tactical missions, and is regularly seen flying in and out of Cambridge airport for its maintenance/modification inputs.

Today Marshall ADG has offices and staff placed all over the world. Each of these offices has their own speciality and was initially set up off the back of a contract with a customer, or purchase of an existing company. The site in North Yorkshire in particular was bought with the direct aim of providing Marshall with a share in the composite structure design and manufacturing market. The composites branch of Marshall ADG is now responsible for the manufacture of helicopter and fast jet pilot helmet outer shells, the gun shield on a type 45 frigate (Royal Navy), UAV airframes (Herti and Raven), along with various submarine, aircraft and even hovercraft structures. Similar to the pattern of metal airframes taking over from wood in the early years of aircraft development, the same trend is now being seen as metals are being replaced with composites.

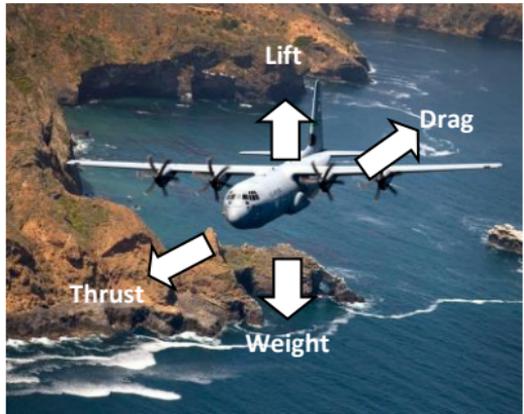
In the simplest of terms Marshall ADG's primary business is the modification, testing, repair and overhaul of aircraft and their sub-structures. The aerospace sector is one of the UK's biggest industries and regularly exports more than

£22bn worth of business every year. The UK is still considered one of the world leaders when it comes to the Engineering sector which stems from a long history of achievements.

### So how do aircraft fly?

When an aircraft is in flight there are four primary forces that act upon it; Lift, Weight, Drag and Thrust.

- Thrust is generated by the engines and propels the aircraft.
- Drag is the resistance caused by the aircraft forcing its way through the air at high speed.
- Weight is dependent on the aircraft size and what passenger/cargo content is being carried.
- Lift is the force created by air flowing over the wings at speed which then supports the weight of the aircraft.



Because of the nature of aircraft, achieving stability and balance in flight is no easy task but a vitally important one. Unlike driving a car on a tarmac road, an aeroplane has no solid surface to help support its weight. Air is always moving, changing pressure and likes to change speed constantly. This means that the distribution of lift and weight across the structure are very important for aircraft stability. Even the largest of aircraft like the Airbus A380 which is 72.72m (238ft 7in) long will require its centre of gravity to be within a range of a few meters of its ideal position. Weight distribution is one of the reasons why fuel is stored in a series of tanks throughout the wings of the aircraft; the fuel can be pumped to different tanks to redistribute weight and help balance the aircraft.

When Marshall ADG are repairing or modifying an aircraft we must quite strictly record the changes made to the weight distribution. If the centre of gravity strays too far out of its safe range, the aircraft can become very difficult to control and in some rare cases become completely uncontrollable. This

factor can be just as important as ensuring the aircraft structure is strong enough to perform the task it was designed for.

### Some questions to think about:

Why did Concorde need a droop nose? No other plane at the time did.

How many countries operate C130 Hercules aircraft as part of their Air Force (roughly)?

### Lift in more detail:

<http://www.grc.nasa.gov/WWW/k-12/airplane/lift1.html>

<http://virtualskies.arc.nasa.gov/aeronautics/3.html>

**Name:** Callum Ward

**Position:** Structural Analysis Engineer

**Company:** Marshall Aerospace and Defence Group

**Educated in:** Mexborough School and Sixth Form College, South Yorkshire

**A-levels (or equivalent):** Maths, Physics, Chemistry

**University:** University of Sheffield

**Qualifications:** MEng Hons, Aerospace Engineering

**My day to day work involves...** assessing the structural integrity of repair schemes designed for C130 Hercules and L1011 Tristar aircraft, as well as advising designers on what repair schemes should be progressed. This work is primarily desk and meeting room orientated but the aircraft I work on are usually right next door to the office so I take the opportunity to visit them regularly. My job role is defined by the department I'm currently based in which is my 3<sup>rd</sup> department in the 3 years I've been at the company.

**Other experience or previous professions:** Part time Retail work, Specialist Cleaning Firm, part time Research Engineer.

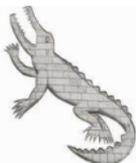
**The best thing about my job is...** seeing tangible results from my day to day efforts.

**The thing I like least about my job is...** industry politics, bureaucracy

**Other careers considered:** Pilot, Officer in the Armed Forces, Motorsport/Motor vehicle Engineer



## 20. Laboratory for Scientific Computing



<http://www.lsc.phy.cam.ac.uk>

### What is scientific computing?

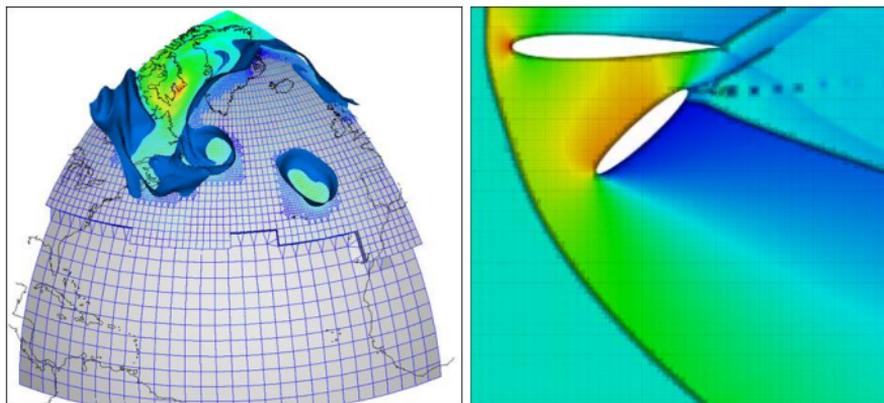
Scientific computing can be used to study anything from the behaviour of atoms in a crystal, to the motion of hurricanes, to the mechanics of black holes.

When scientists study the natural world they do experiments and make observations. From these observations they come up with mathematical equations, or models, which describe physical phenomena. These models can be anything from classical models like Newton's laws of motion, to quantum mechanical models like the Schrödinger equation. The job of scientific computing is to solve these equations on a computer and look at how the models behave. This involves a mixture of physics, chemistry, mathematics, and computer science.

### How do fluids work?

If you watch the weather report on television, you will see a map which shows a prediction of how rain clouds and temperature fronts are going to behave. How do meteorologists come up with these predictions?

The atmosphere behaves like a huge fluid, constantly in motion and exchanging heat and mass with the ocean. This type of system is modelled with a branch of physics called fluid mechanics. The equations of fluid mechanics are simple – you can write them down in a few lines. You can use them to describe the mixing of milk into a cup of coffee, the detonation of an explosive gas, the motion of a hurricane, or the airflow over an aeroplane's wings. A lot of the work done by LSC involves fluid phenomena like these. But solving these equations for a particular case is hard. And for complex fluid systems, there are processes which must be modelled in addition to the fluid mechanics, such as chemical reactions and thermodynamics.

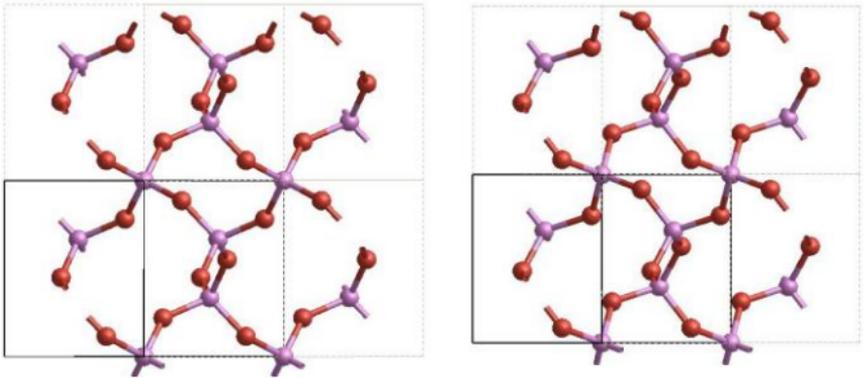


**Figure 1:** Left: part of a global atmospheric simulation. Right: supersonic flow over a payload dropped from an aerofoil, representing the wing of an aeroplane.

### How do you predict properties of materials?

The atmosphere model described above needs to represent properties of water and air in a realistic way – for example, how they behave under changes in pressure or temperature. Other simulations will likewise need to know how a particular material changes shape or size when it is put under stress. Rocks, paper, steel, aluminium or other materials will all behave differently. This type of behaviour is described by a model called an 'equation of state'. Sometimes simple models (such as an 'ideal gas') work well. Other times, equations of state are fitted to experimental measurements. Computer 'experiments' are also a useful source of information. Methods based on quantum mechanics can predict the balance of forces present in a crystal, and hence an equation of state for the crystal.

For example, *Figure 2* shows the predicted atomic structures of quartz at atmospheric pressure and at 10GPa (about 100,000 times atmospheric pressure).



**Figure 2:** Repeating unit of quartz crystals at atmospheric pressure (left) and 10GPa (right)

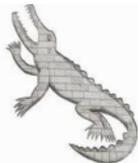
### How do you find solutions faster?

Scientific computing is a multi-disciplinary field. Thinking about science problems is only one part of the field. Another part is thinking about programming and computer science problems. One big problem is how to solve equations quickly. It's no use having a brilliant computer model of a hurricane if it takes years and years to give a prediction. For this reason scientific computing takes place near the forefront of high performance computing technology.



**Figure 3:** An NVIDIA Tesla graphics card, one of the first GPUs designed specifically for general purpose and scientific computing.

## **21. Dr Jane Blunt**



### **Why do things fall apart?**

You are probably familiar with the term ‘forensic science’ in the detection of crime, looking at items such as fingerprints, DNA evidence and footprints.

The word ‘forensic’ means ‘belonging to a court of law’, and in this exhibit you will see some of the work of physicists and engineers in examining the evidence after accidents where structures or equipment have broken. After a catastrophe such as an aeroplane or rail crash, we always want to know whether there was a structural failure, and if so, why, so as to prevent it from happening again.

We can examine the design and decide whether the calculations were done correctly, to see whether the design was good enough. There are International Standards that must be met for the design and construction of safety-critical items such as pressure vessels. The item must have been built according to the specification, and we would examine the evidence to decide whether the conditions had been met.

Chemical analysis of the matter can show us whether the correct material was used in making the item. Examination of the material under a microscope can show us whether the material was in the correct condition, or whether it had been mistreated either before manufacture or afterwards.

The broken surfaces contain a lot of clues. We can see, often with the naked eye, in which direction the crack was running, and where it started from. Examination under a microscope can tell us what sort of fracture it was, which further helps us to decide what went wrong.

Destructive tests, in which we break pieces of the material and measure the forces needed to break them, will give us another vital piece of information about the failure.

Finally we can put all the evidence together and decide:

- Was the design good enough for the service?
- Was it built correctly and from the right materials? Was it misused?
- Was there an unusual event?

## PHYSICS AT WORK 2016

The Physics at Work Exhibition is a major annual event at the Cavendish Laboratory. The primary aim of this exhibition is to stimulate interest and encourage wider participation in physics amongst 14-16 year olds by showcasing the many and varied ways in which physics is used in the real world. This annual event is extremely popular with schools, with the 2300 available places for students fully booked within a couple of weeks of the invitations being sent out.

The Physics at Work 2016 Exhibition is an integral part of the Cavendish Laboratory's Educational Outreach Programme.

This booklet has been created to accompany the Physics at Work 2016 Exhibition. It is designed to introduce the exhibition and supplement the event by providing information to accompany each of the exhibits. The booklet can be used in many different ways, including:

- consolidation or extension of attendance at the 2016 Physics at Work Exhibition
- introductions to topics
- careers discussions
- extra material to support, encourage and challenge those students that complete curriculum work ahead of their peers

An on-line version of this booklet is available through the 2016 Physics at Work website at:

<http://outreach.phy.cam.ac.uk/programme/physicsatwork/booklet2016/>

For more information about physics-based activities and events in the East of England please contact:

Educational Outreach Officer, Cavendish Laboratory, University of Cambridge, J J Thomson Avenue, Cambridge, CB3 0HE

Tel: 01223 333318 Fax: 01223 766360

E-mail: [outreach@phy.cam.ac.uk](mailto:outreach@phy.cam.ac.uk)

Or visit: <http://www-outreach.phy.cam.ac.uk>

Twitter: @physicsoutreach



Kindly supported and sponsored by



**THE CAVENDISH LABORATORY**



**UNIVERSITY OF  
CAMBRIDGE**



**IOP**

**Institute of Physics  
East Anglia Branch**



**The MathWorks™**  
*Accelerating the pace of engineering and science*

**EPSRC**

Engineering and Physical Sciences  
Research Council