Exhibitors List 2017 (in route order):

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

IOP | Institute of Physics
East Anglia Branch

UNIVERSITY OF CAMBRIDGE
Cavendish Laboratory

&

The Cambridge Physics Centre

Present the

2017
Physics at Work Exhibition

at

The Cavendish Laboratory
Madingley Road
Cambridge

On

Tuesday 19th September
Wednesday 20th September
Thursday 21st September

Organised by:

Dr Lisa Jardine-Wright and Jacob Breward Butler

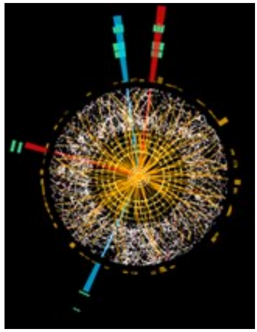
Educational Outreach Office, Cavendish Laboratory

Facilities and Technical Assistance:

The Cavendish Laboratory staff

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.

Cavendish Laboratory

1. Semiconductor Physics Research Group

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

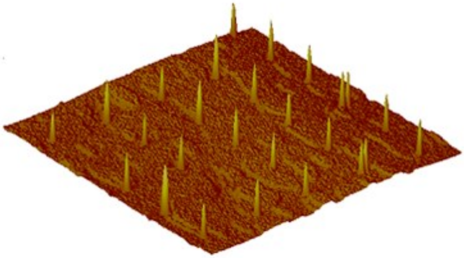
Electricity seems very simple – you just flick a switch and there it is – but how often have you thought about what is happening to the electrons that make up that electricity? The electrons' behaviour can change depending on what material they are in. Materials can be divided into three categories according to their ability to conduct electrons: insulators, conductors and semi-conductors. 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.

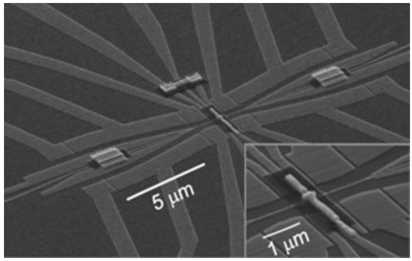


← Figure 1:

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.

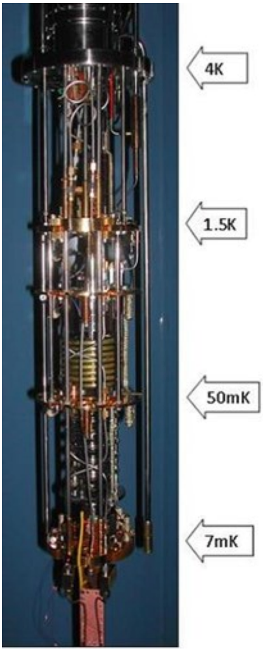


However we do it, the electron behaviour is very different compared to that in three dimensions. Quantum mechanics starts to take over from classical physics, with lots of strange effects such as quantisation (measured quantities can only be multiples of a certain value) and wave-particle duality (for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



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.

Name: Mrs Melanie Tribble

Position: Research Associate

Company: Cavendish Laboratory

Educated at: Lordswood 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.

University of Cambridge

2. The Tech Partnership

http://www.ttp.com

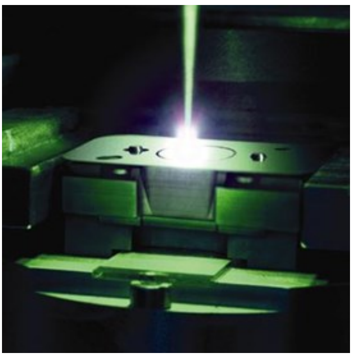
Innovation

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.

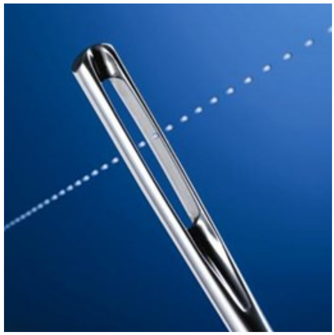
Physicists play a major role at TTP, and can work on a wide range of projects from printing and laser technology through to confectionery packaging.



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.

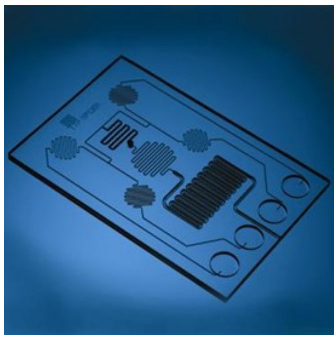
By contrast, TTP's 'electronic aerosol' technology employs a piezoelectric actuator to oscillate a perforated membrane, contacting the liquid to be sprayed, at ultrasonic frequencies. The high frequency oscillation causes oscillatory pressure fluctuations that eject the liquid through the holes. One 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: 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 Weapons Establishment

http://www.awe.co.uk

Twitter: @AWE_plc

What is AWE?

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 (CTBT), counter terrorism and the country's national nuclear security. It is a centre of scientific and technical excellence with world-leading facilities, such as the Orion laser.

Atomic Physics

Understanding physics is at the heart of what we do at AWE. From our commitment to the country's national nuclear security through to counter terrorism and the lifecycle of the deterrent; it depends on our knowledge of this fundamental part of nature.

Understanding the basic components of an atom is enormously important in understanding their behaviour. The electrons determine the types of reactions an element can undergo and what new compounds it can form. The protons and neutrons determine whether an atom will be stable, and also they affect the types of compounds an element can form and how they will behave.

The idea that all matter is made up of atoms is very old, dating back to the ancient Greeks. However, it wasn't until the 20th century until the modern idea of an atom was established.

It wasn't long before experiments showed that the atom had internal components; the electron was discovered by J.J. Thomson in 1898. A new component of the atom would be found: the nucleus…

Nuclear physics

At the centre of every atom is a cluster of particles, known as the nucleus. The nucleus is tiny (approximately 0.0000000000001 cm wide), but it has a major impact on the behaviour of the atom.

The study of the nucleus and its constituent particles is called nuclear physics, and its origins can be traced back to well over 150 years ago. However, ultimately it was Rutherford who discovered the existence of the nucleus in 1911 with his famous gold foil experiment.

Since then, numerous scientists have contributed to our understanding of this fundamental area of physics, from the discovery of the particles inside the nucleus, the proton and neutron, to the dawn of the quantum age and the model of the nucleus as we now know it.

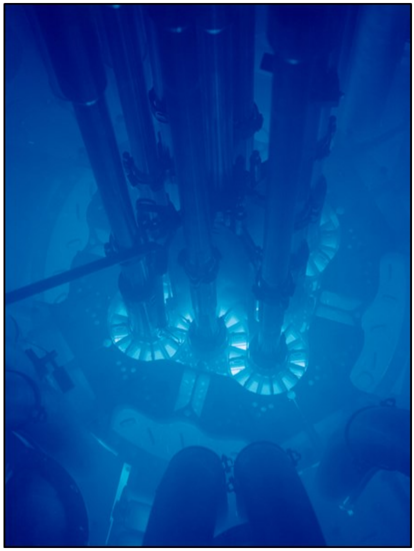


Figure 1:
Advanced Test Reactor core, Idaho National Laboratory. Image by Argonne National Laboratory.

Understanding these nuclei allows us to do remarkable things such as producing large amounts of energy (by breaking apart or fusing nuclei together), analysing objects using particles emitted by the nucleus and using detectors to keep the nation safe from dangerous materials.

Radioactivity

Some nuclei are intrinsically unstable and will undergo radioactive decay by emitting energy and attempting to become stable. This energy can take the form of gamma rays (highly energetic electromagnetic waves) or particles (such as alpha, beta and neutrons). Each of these emissions will have a signature energy output that corresponds to the type of decay that caused it. The study of these emissions can tell us a lot about the internal structure of the nuclei.

At AWE we can employ radiation detectors to observe these phenomena and identify what materials are present, supporting our commitments to the CTBT and national security as a whole.

Your task for today is to help us replicate Rutherford's famous gold leaf experiment and to race to tell us what is in the heart of our giant atoms…

NAME: Dave
TITLE: Graduate – Mechanical Engineer
SQA HIGHERS: Mathematics, Physics, Chemistry, Biology, Geography, English, Music, Drama, (+SQA CSYS Mathematics)
QUALIFICATIONS: BEng Hons Mechanical and Powerplant Systems Engineering
MY DAY TO DAY JOB INVOLVES: Coordinating different elements of engineering projects and schedules between departments.
BEST THING ABOUT MY JOB: Experience in working with some unique technology, and interaction with subject matter experts to provide innovative solutions to practical and logistical challenges.

NAME: Ed
TITLE: Graduate – Finance and Business Management
A-LEVELS: Further Maths, Physics, Chemistry
QUALIFICATIONS: BSc in Mathematics
MY DAY TO DAY JOB INVOLVES: Providing financial and analytical support to projects in order to align with budgets and schedules.
BEST THING ABOUT MY JOB: Experiencing how multi-million pound projects are organised, monitored and controlled, whilst also having the opportunity to be involved and potentially improve areas of this management.

NAME: Ellis
TITLE: Physicist
A-LEVELS: Physics, Chemistry, Mathematics, Further Mathematics
QUALIFICATIONS: BA Natural Sciences
MY DAY TO DAY JOB INVOLVES: Using computers to model physical processes.
BEST THING ABOUT MY JOB: Learning about new parts of physics every day and using that to solve problems.

NAME: Joe
TITLE: Materials Compatibility Scientist
A-LEVELS: Physics, Chemistry, Maths and Further Maths
QUALIFICATIONS: MSci and PhD in Metallurgy and Materials Science
MY DAY TO DAY JOB INVOLVES: Experimental work assessing the long life compatibility and behaviour of multi-material systems
BEST THING ABOUT MY JOB: Interacting with a wide range of interesting and strange materials and studying their physical and chemical behaviour.

NAME: Josh
TITLE: Radiometric Physicist
A-LEVELS: Physics, Chemistry, Mathematics and Further Mathematics
QUALIFICATIONS: BSc Hons Physics
MY DAY TO DAY JOB INVOLVES: The design and implementation of experimental measurements of radioactive material.
BEST THING ABOUT MY JOB: Working with world experts in my field and excellent opportunities to travel.

NAME: Ryan
TITLE: Radiometric Physicist
A-LEVELS: Pure Maths, Physics, Chemistry, History
QUALIFICATIONS: MPhys in Physics
MY DAY TO DAY JOB INVOLVES: The design and implementation of experimental measurements of radioactive material.
BEST THING ABOUT MY JOB: Bringing together experimental data and relevant subject knowledge to perform quantitative analysis.

NAME: Sarah
TITLE: Environmental Monitoring Specialist
A-LEVELS: Chemistry, Biology, Geography
QUALIFICATIONS: MChem in Environmental Chemistry
MY DAY TO DAY JOB INVOLVES: Writing environmental monitoring reports as well as organising and managing environmental projects.
BEST THING ABOUT MY JOB: Going out to collect environmental samples and seeing the whole process from collection to analysis to reporting.

NAME: Sef
TITLE: Physicist
A-LEVELS: Maths, Physics, Chemistry
QUALIFICATIONS: BEng hons Electronic Engineering
MY DAY TO DAY JOB INVOLVES: Working with software to support physics applications.
BEST THING ABOUT MY JOB: Working with specialist equipment and modifying its functionality to fulfil necessary requirements for physics experiments.

Cavendish Laboratory

4. Quantum Matter Group

http://www.qm.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 YBa2Cu3O7 although the material sometimes loses oxygen.

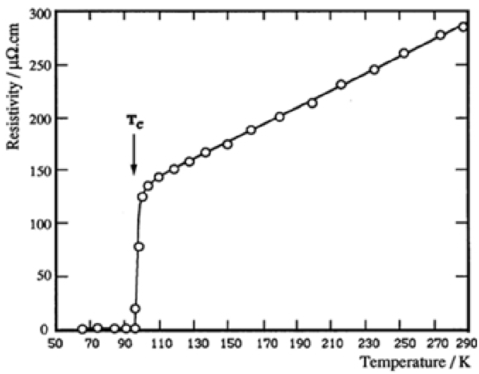


Figure 1: *The variation in resistivity of YBa2Cu3O7 with temperature.*

Figure 1 shows the sudden disappearance of the resistivity of YBa2Cu3O7 on cooling the sample. Other ceramic compounds containing copper also give high transition temperatures. The cuprate superconductor with the highest transition temperature is HgBa2Ca2Cu3O8+d, which shows superconductivity at 160 K [-110 ^{o}C] under pressure.

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.

Figure 2:
A $YBa_2Cu_3O_7$ superconducting disc being "levitated" by a permanent magnet.

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°C and –269°C, and the high temperature superconductors are brittle ceramics, which means making wires from them is challenging.

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

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.

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

Cavendish Laboratory

5. 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.

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*

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?
- **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?

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

- **Technology**: What are the best materials to use for different parts of the car (e.g. tyres, body shell, axle and bearings)? Why?

The Team Crocodile Fuel-Efficient Car

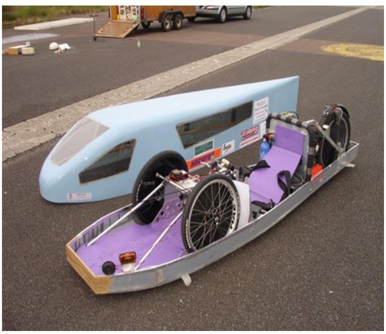


Figure 2: *Inside Team Crocodile's fuel-efficient*

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 1¾”) 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 2018 Exhibition, and on our website.

Team Crocodile is still 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 Mallory Park Racing Circuit.

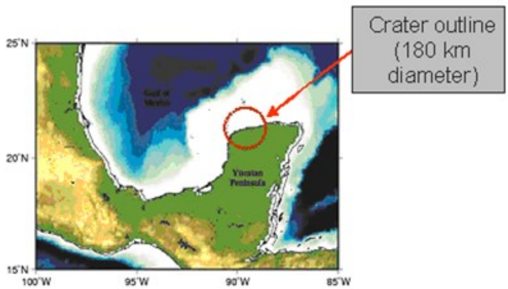
Bullard Laboratory

6. Earth Sciences (Dept. of)

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

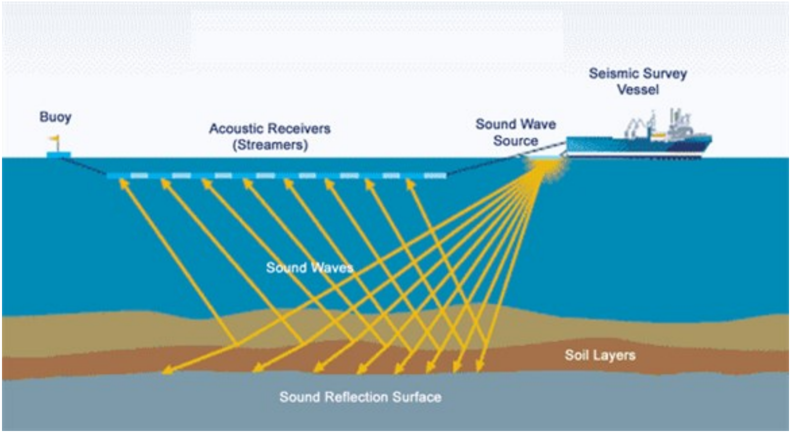
Seismics - A look at Global Catastrophe

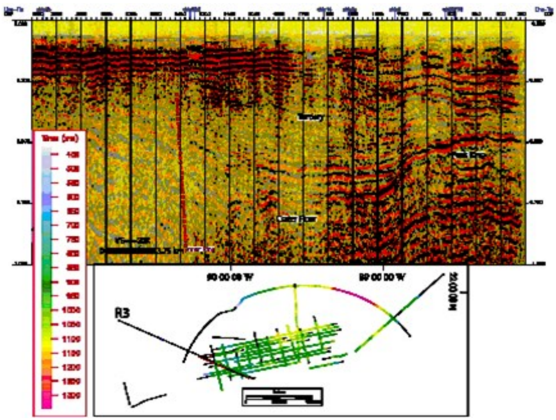
Sixty-five million years ago a 10 km diameter meteor crashed into the Yucatan Peninsula of Mexico leaving a 200 km wide crater. This crater is known as the Chicxulub crater (it is named after the small fishing village that is now at its centre). It is one of only three known impact craters on Earth with 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.





7. MathWorks

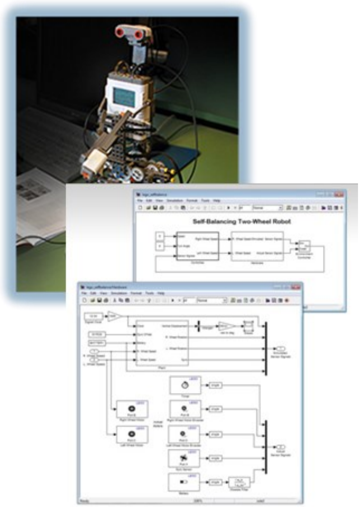
http://www.mathworks.co.uk

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 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.

Name: Dr Gareth Griffiths

Position: Software Developer

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)

Cavendish Laboratory

8. 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.

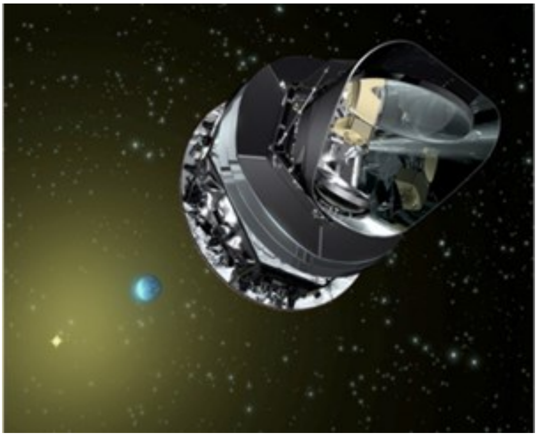


Figure 1: *Artist's impression of the Planck satellite showing the Earth and Sun in the background.*
Credit: European Space Agency

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

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

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.

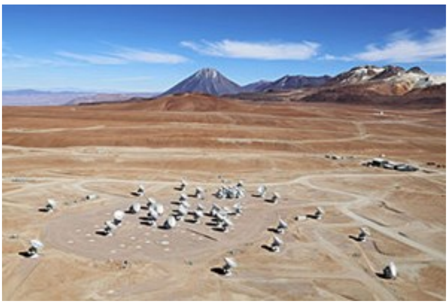


***Figure 3**: The 66 high-precision dishes of the ALMA array.*
Credit: ESO/Clem & Adri Bacri-Normier

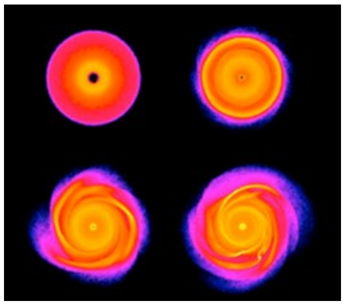


***Figure 4:** Simulation of planets forming out of a swirling disk of matter orbiting a new star.*
Credit: T Quinn, University of Washington

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.

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): chandra.harvard.edu

Planck Satellite mission: sciops.esa.int/index.php?project=PLANCK

SKA Telescope: skatelescope.org

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.

9. Rolls-Royce

http://www.rolls-royce.com

What we do




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

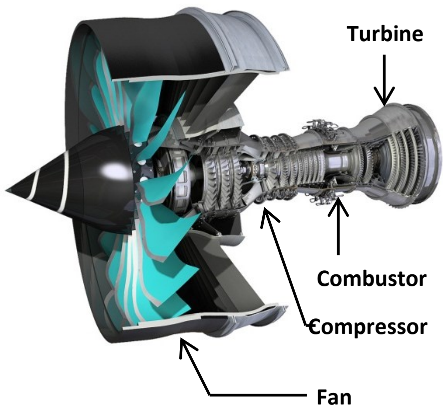
Rolls-Royce designs, develops, manufactures and services integrated power systems for use in the air, on land and at sea.

The Civil aerospace business is a major manufacturer of aero engines for the commercial large aircraft and corporate jet markets. We're also the world's second largest provider of defence aero-engine products and services.

In the Marine market we are a world leader in vessel design, integration of complex systems and supply support of power and propulsion equipment. 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.



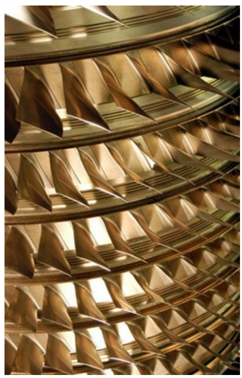
Fans

The fan in a gas turbine produces 80% 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.

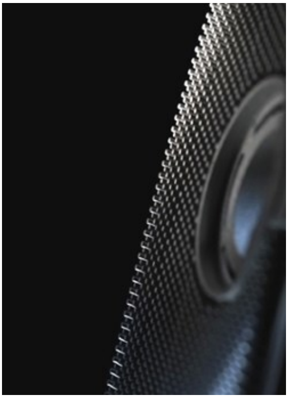
Fan efficiency is an increasingly important contributor to overall improvements in engine efficiencies.

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

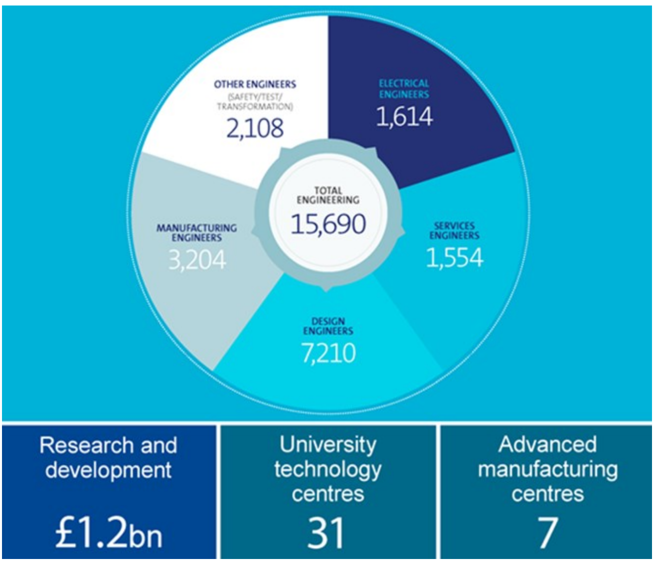
Fuel and air are mixed and burned within the combustion chamber to convert chemical energy of the fuel into thermal energy within the gas-stream prior to entry into the turbines.

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



Name: Jenny Doody

Position: Manufacturing Engineering Graduate

Educated in: Queen's University Belfast

A-levels: Maths, Physics, Spanish, Music

Qualifications: MEng Mechanical Engineering

Day to day work involves… My current attachment centres on Continuous Improvement and is based in the Rotatives business (where all the rotating shafts, discs and drums in the jet engine are manufactured). Meeting targets, achieving zero defects on parts and driving down arrears are the overall key objectives.

The best thing about my job is… The mix of shopfloor and office work – I am never sitting looking at a computer too long!

Other careers considered… Maths teacher

Name: Mark Atkins

Position: Engineering Graduate

Educated in: Loughborough University

A levels: Maths, Physics, Geography

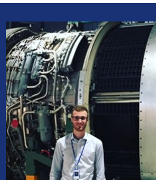
Qualifications: MEng Aeronautical Engineering

Day to day work involves… I'm on a graduate placement which involves 4 four month placements throughout the company. I'm currently part of the Design for Assembly Team for the UltraFan™. This involves looking at the current processes and steps undertaken in assembling our current large engines and identifying how to reduce or remove them. A lot of time is spent on the shop floor talking to the fitters and people from various UltraFan™ focused teams. The idea is to have an engine that can be put together like Lego in a new purpose built facility.

The best thing about my job is… Being involved with changing and potentially revolutionising how Rolls-Royce will build civil large engines in the future.

The thing I like least about my job is… The amount of walking between the shop floor and different officers.

Other careers considered: RAF Engineering Officer



Name: Andrew Holt

Position: Engineering Graduate

Educated in: Imperial College London

A levels: Maths, Further Maths, Physics

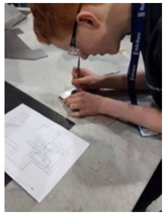
Qualifications: MEng Aeronautical Engineering

Day to day work involves… I'm on a graduate placement which involves 4 four month placements throughout the company. I'm currently working on a design and make project to improve the manufacturing process of turbine blades. I've previously worked in Performance, Combustion and Nuclear areas of the company.

The best thing about my job is… Being able to contribute to big engine projects, and getting to see some really interesting technology like jet engine turbine blades and combustion designs!

The thing I like least about my job is… sometimes feeling a bit overwhelmed by the complexity of engineering work.

Other careers considered: Airline pilot



Name: Stephen Allen

Position: EfS Advanced Technical Apprentice

Educated at: da Vinci Community School (Derby), University of Derby

GCSEs: English, Maths, Triple Science, French

Qualifications: BTEC L3 Engineering (In 1st 2 years of Apprenticeship), moving onto Foundation Degree.

Day to day work involves…

As a Technical Apprentice, I have around 7-8 3 month placements in different areas of the Civil Aerospace Engineering part of Rolls-Royce. Currently, I am in Service Engineering, looking after the engines whilst they are in service, dealing with a variety of in-flight issues, from urgent requests to more long-term issues.

The best thing about my job is…

I can learn whilst getting paid! 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, whilst learning about how a prestigious organisation like Rolls-Royce operates, as well as the configuration and functioning of their engines.

University of Cambridge

10. Material Science and Metallurgy (Dept. of)

http://www.msm.cam.ac.uk

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 19th 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

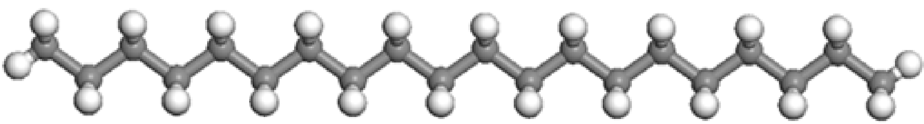


Figure 1: *Linear chain of poly(ethylene). The monomer unit is $CH_2{=}CH_2$.*
Image courtesy of DoIT PoMS, Department of Materials Science and Metallurgy, University of Cambridge.

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).

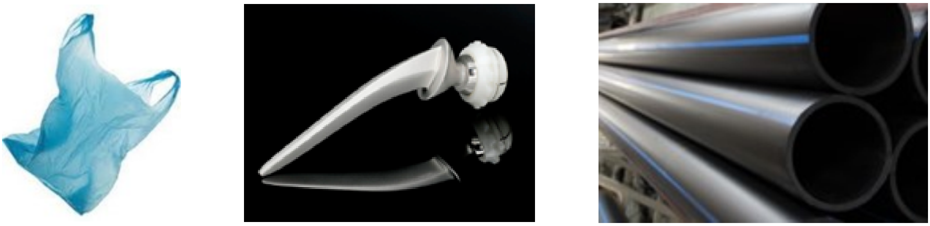


Figure 2: *Polyurethane has a vast array of applications.*

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!

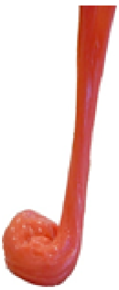
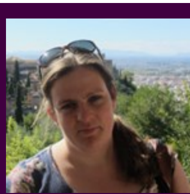


Figure 3:
PVA glue, otherwise known as poly(vinyl alcohol), with borax added to form cross-links. Here, the polymer has been allowed to stretch slowly under its own weight.

Figure 4: *A shattered polymer squash ball – cooling to $-196^{o}C$ 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.

11. BP

http://www.bp.com

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).

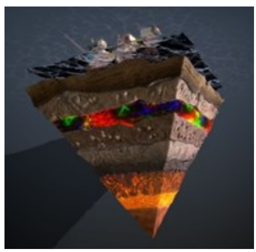


Figure 1:
An image of the earth is built through seismic imaging

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.

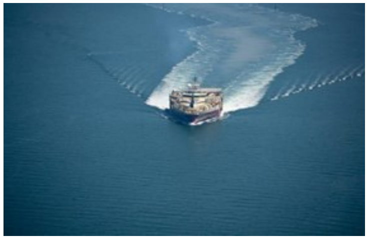


Figure 2: *Acquisition of seismic data on land and sea*

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 in 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.

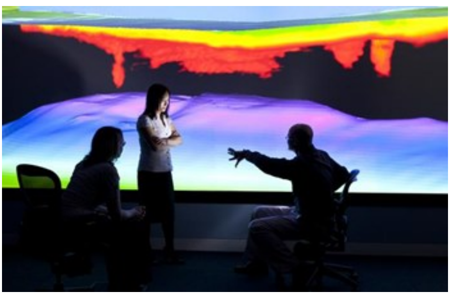


Figure 3: *3D seismic images are visualised and used to find oil and gas reserves*

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.

Cavendish Laboratory

12. 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.

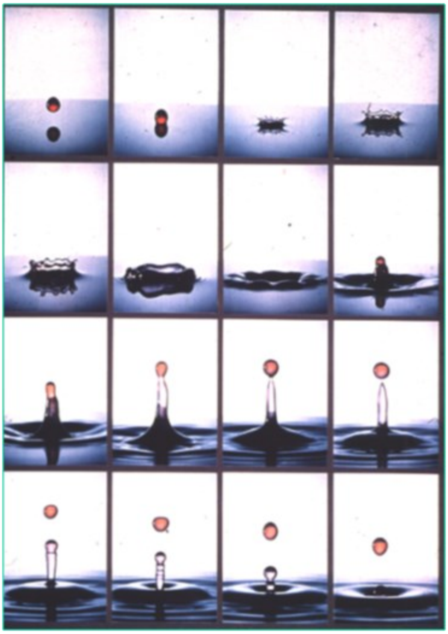


Figure 1: *A sequence showing a drop of red-dyed water falling into a pool of blue-dyed water.*

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.

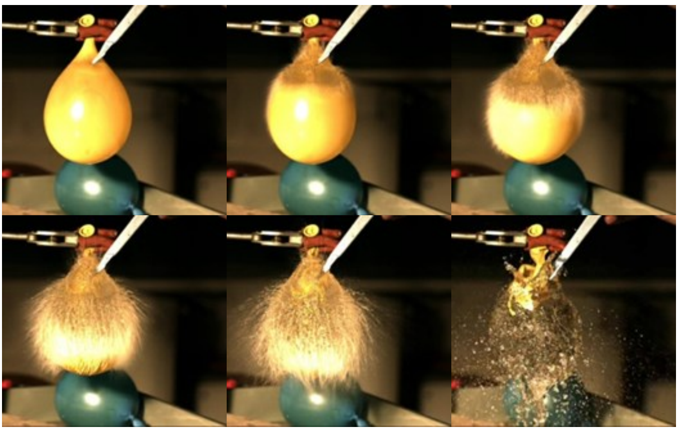


Figure 2: *A sequence of images from a high-speed video recording of a water balloon being burst. Notice how the skin of the balloon 'unwraps' leaving a ball of water that subsequently falls away.*

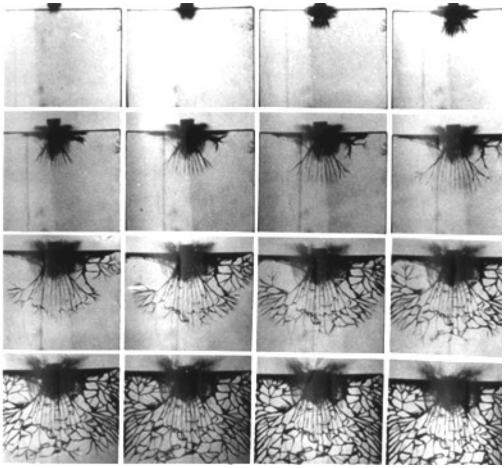


***Figure 3**:*
The propagation of cracks in a 50 x 50 x 6.2mm sheet of toughened windscreen glass, after impact with a lead airgun pellet at the top. The time between frames is two millionths of a second.

13. Isaac Physics

http://www.isaacphysics.org

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!

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.

Cavendish Laboratory

14. 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".

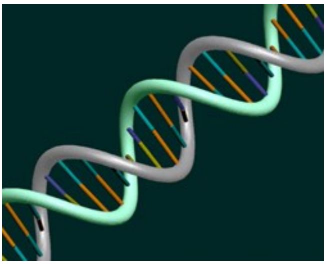
In biology, the rules are well known: molecules obey chemistry. But how these molecules and their reactions come together is phenomenally complex, even within a single cell, and we can make progress by developing the concepts that have been successful in other "complex systems". It is here that physics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

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.



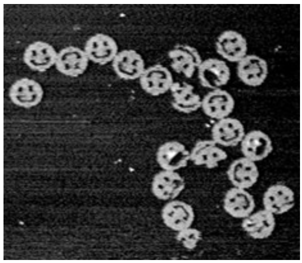


Figure 1: *DNA origami of viruses made by Paul W.K. Rothemund from a harmless virus-DNA. He "pinched" it into shape with "staples" made from much shorter DNA strands (ref.: P.W.K. Rohemund, Nature, Vol 440|16 March 2006|doi:10.1038/nature04586).*

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).

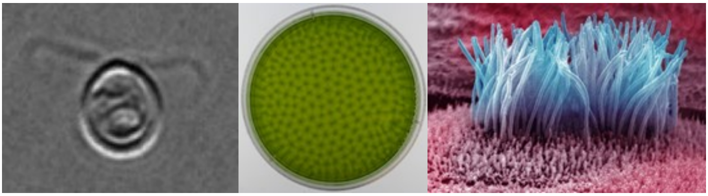


Figure 2: *The swimming microalga Dunaliella moves by beating two cilia. The cell is also bottom-heavy, so its swimming is biased in flows by a combination of gravitational and viscous torques (gyrotaxis). Gyrotaxis gives rise to the beautiful patterns shown in the centre (a top view of a Petri dish). 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/).

University of Cambridge and Addenbrooke's Hospital

15. Computational Radiotherapy

http://www.comprt.org

Computational radiotherapy combines computing, engineering, mathematics, medicine and physics to improve treatment of cancer.

Cancer and Its Treatment

An average person is made up of more than ten million million cells, which are continually being replaced. Cancer starts when the processes controlling cell replacement go wrong, and faulty cells are produced in large numbers. These faulty cells can build up in the blood, or may form lumps, known as tumours. The physics approach to treatment is to try to destroy tumour cells by firing large amounts of energy at them. This energy usually comes from X-rays, when the treatment is called radiotherapy, but can also come from sub-atomic particles.

Before radiotherapy begins, a three-dimensional image is needed of the patient's insides, close to the tumour. One of the most common types of image is known as a computed-tomograpy scan, or CT scan. This involves sending X-rays through the patient from many positions and angles, and recording the shadows cast by different body parts. At each position along the patient, the result is a pattern of wavy lines, called a sinogram. Mathematics and computers are used to take information from the sinograms, and to build images of slices through the body.

A doctor uses the CT scan to make a plan for giving a large dose of energy to the tumour, and avoiding damage to healthy body parts. A patient typically attends twenty to forty treatment sessions, spread over four to eight weeks. At each session, the patient is carefully positioned, to make sure that the X-rays, fired from many directions, hit their target. A low-quality CT scan may be recorded to help with this.

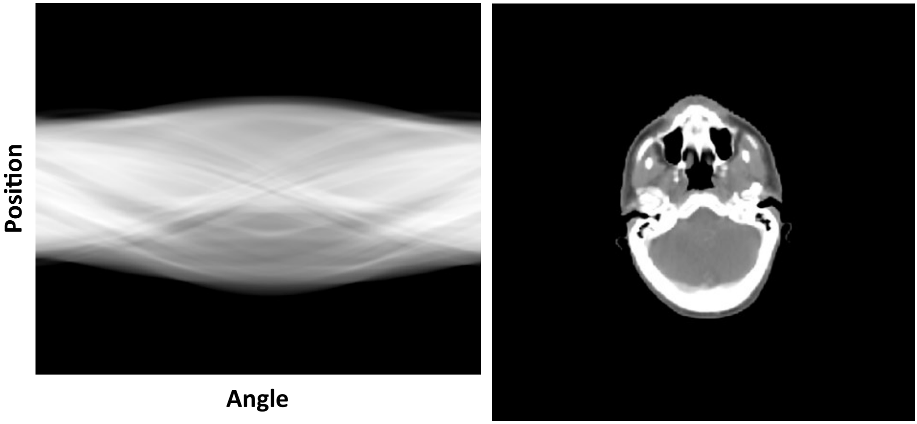


Figure 1: *A sinogram and the resulting image, for a slice through the head at the level of the jaw.*

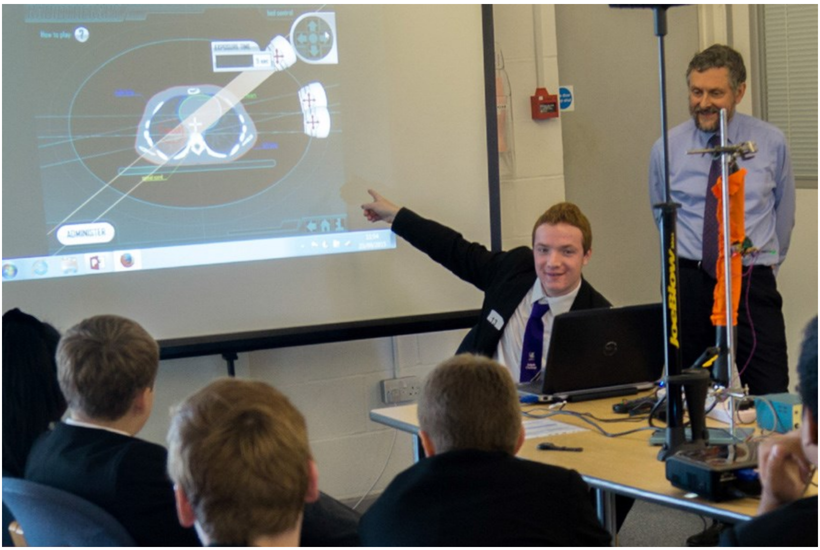


Figure 2: *A school student tries his hand at radiotherapy planning, during a visit to the Physics at Work Exhibition. The radiotherapy game is available at: http://insidestory.iop.org/insidestory_flash1.html*

Improving Radiotherapy

A problem in radiotherapy is that body parts can move about inside a person, for example as a result of breathing, eating or walking. Tumours are accurately targeted, but the dose to nearby body parts can be different from planned. If the dose is higher than planned, this can result in side effects, which may badly affect a patient's life. If the dose is lower than planned, then the dose to the tumour could have been made higher, possibly making the treatment more effective.

Researchers at Cambridge aim to improve radiotherapy, by understanding actual doses to healthy body parts. They focus on cancer of the prostate, which is just below the bladder in boys and men, and on cancers of the head and neck. Using physical and computer models, they study how body parts can move and change shape. They develop methods for automatically outlining body parts on CT scans, and test these methods on real and fake data. They perform dose calculations. They analyse information from patients about treatment side effects.

Figure 3: *An undergraduate student investigates shape changes of the rectum, using a physical model. The rectum is part of the digestive system, and can be damaged during radiotherapy for prostate cancer.*

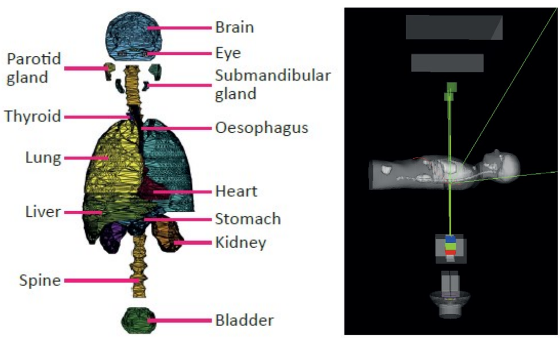


Figure 4: *Computer modelling of body parts, and of the radiotherapy setup.*

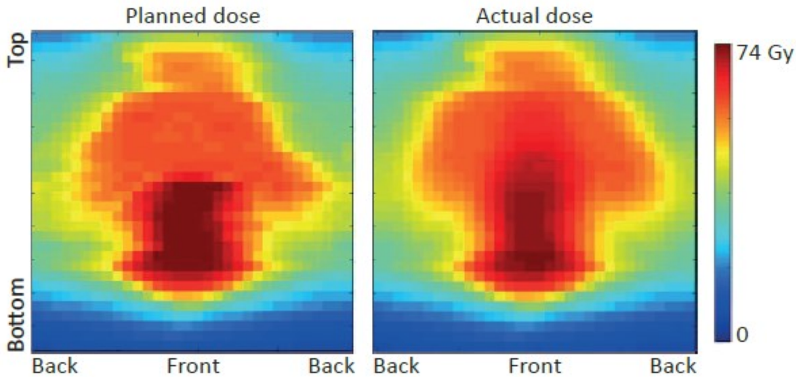


Figure 5: *Maps of planned and actual dose to the surface of the rectum, for a patient treated for prostate cancer. The rectum is below and behind the bladder, and the part where the dose is highest is in contact with the prostate. Rolling up a map, and joining the back edges, gives the rectum's tube shape.*

Name: Megan Wilson
Posistion: PhD student
Educated at: Wilberforce Sixth Form College, Hull
A Levels: Mathematics, Further Mathematics,Physics, Chemistry, and (AS) Biology
University: Emmanuel College, Cambridge
Qualifications: BA and MSci Natural Sciences (Physics)
My day-to-day work involves... writing and using lots of Python code. I analyse data from diagnostic computed-tomography (CT) scans of real patients with cancer, and use the results to generate synthetic radiotherapy treatment scans. These synthetic scans can be used to test algorithms that automatically outline important organs near to the cancers to allow calculation of their radiation dose during treatment.
The best thing about my job is... the freedom in research to explore something that no one has done before or has answers to, and knowing that my problem-solving skills will help real people in the future.
The thing I like least about my job is... unidentified bugs in my code!
Other careers considered: Medicine

16. 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?

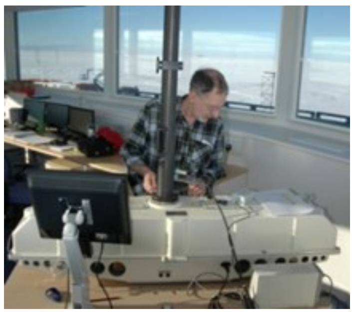


Figure 1: *BAS scientist Jon Shanklin makes an ozone measurement at Halley station.*

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

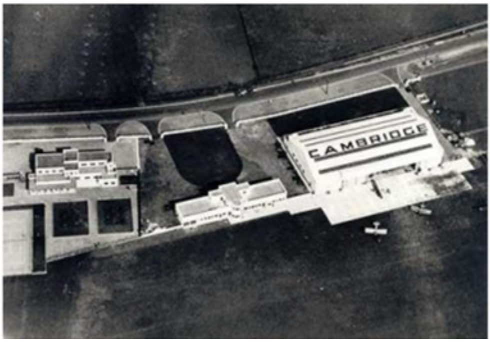
Name: Tim Barnes
Position: Data Manager
Company: British Antarctic Survey
Educated in: Hills Road Sixth Form College, Cambridge
A-levels (or equivalent): Maths, Physics, General Studies, Further Maths (AS-Level)
University: University of Reading, Anglia Ruskin University
Qualifications: BSc (hons) Physics 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.
The thing I like least about my job is... Paperwork.

17. Marshall Aerospace and Defence Group

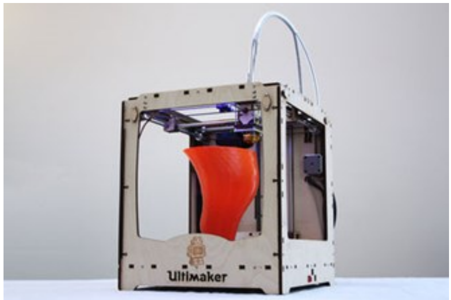
http://www.marshallgroup.co.uk
http://www.marshallaerospace.com

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. Sir Arthur Marshall 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.



To give you an idea of the challenging projects Marshall ADG delivered, here are two of those within many: 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.

Additionally, 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

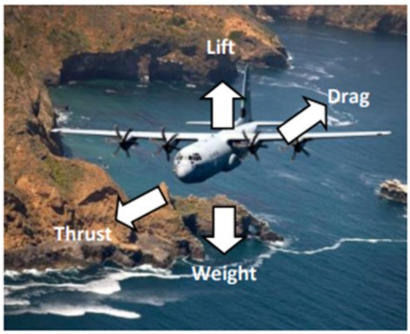


submarine, aircraft and even hovercraft structures. Similar to the pattern of metal airframes taking over from wood in the early years of aircraft development, the same trend is now being seen as metals are being replaced with composites. We also demonstrate on the day the use of additive manufacturing and will print out parts on a Ultimaker 3D Printer.

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 83 £22bn worth of business every year.

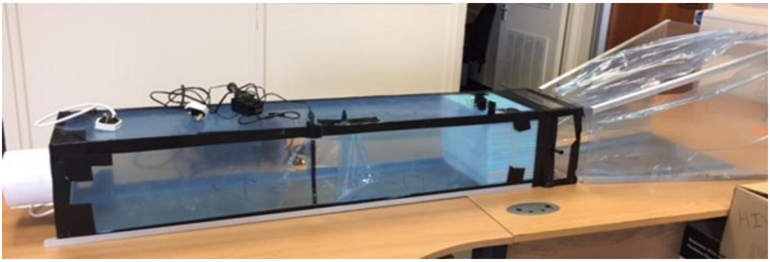
So How do Aircraft Fly?

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.



We will demonstrate and measure lift generation in a wind tunnel and visualize air flow (turbulent/laminar flow and stall) around different shapes (bloc, sphere, wing sections).

Some Questions to Think About:

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

Think about the challenges engineers faced in modifying an aircraft and make it fly again.

What are the challenges with current materials use on airplanes?

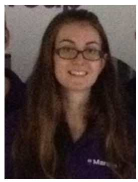
What physics law that you might know help generating lift?

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 other platform including composite platform, 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 3rd 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



Name: Celine Dumas
Position: Avionics Design Engineer
Company: Marshall Aerospace and Defence Group
Educated in: France
A-levels (or equivalent): Maths, Physics, Chemistry, Engineering Science, English, French, Spanish
University: Ecole Centrale Nantes
Qualifications: MEng Hons, Product Development and Finance
My day to day work involves... finding solution to customer requirements to modify their aircraft. This involves market research, technical proposal writing, flow down of requirements to suppliers, use of system engineering technique. Another aspect of my role is to integrate the different system together. 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 3rd department in the 1.5 years I've been at the company.
Other experience or previous professions: Manufacturing Engineer at Airbus and Rolls-Royce
The best thing about my job is... working from a concept to a certified solution using system engineering
The thing I like least about my job is... industry politics, bureaucracy
Other careers considered: Scientist, Production Leader, Project Manager

Cavendish Laboratory

18. Biological and Soft Systems Research Sector

http://www.bss.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?

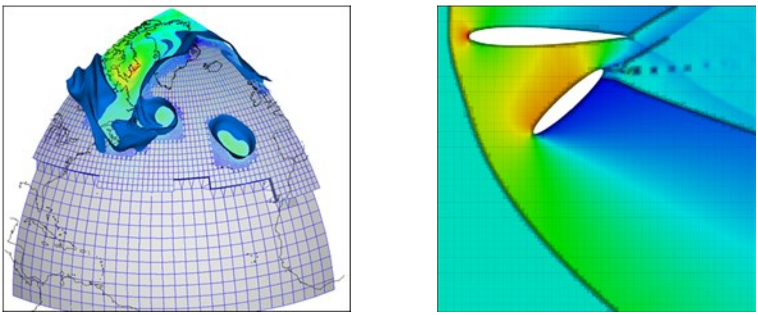


Figure 1: *Left: part of a global atmospheric simulation. Right: supersonic flow over a payload dropped from an aerofoil, representing the wing of an aeroplane.*

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.

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).

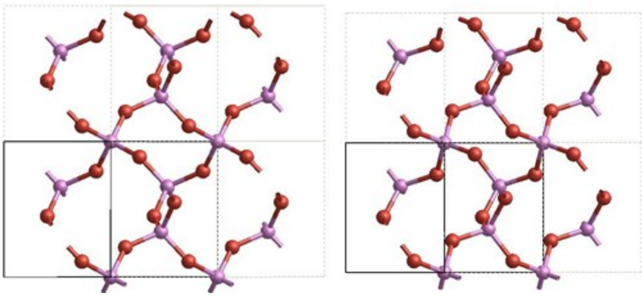


Figure 2: *Repeating unit of quartz crystals at atmospheric pressure (left) and 10GPa (right)*

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.

19. 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?

Or

- Was there an unusual event?

Cavendish Laboratory

20. Many-body Quantum Dynamics

http://www.manybody.phy.cam.ac.uk

Sonic Tractor Beams & Optical Tweezers: Lifting the Tiniest Objects

In many fields of experimental science, manipulating the subject of your experiments can be quite a challenge. This can be for many reasons: perhaps you study chemical samples that have to be kept pure, so that you can't touch them; or perhaps you work with lab rats that will bite if they're picked up wrong. One especially interesting challenge is the manipulation of extremely tiny and delicate things. Normally for lifting small objects you might use equipment like this:

Figure 1: *Tweezers for lifting small objects.*

But what if you work with single cells? Even if you could build small enough tweezers you couldn't grip the cell without exerting enough force to destroy it. In our group, the problem is even more extreme: we need a system to manipulate clouds of single atoms, that are far too tiny for any normal tweezers. Ideally we need a tractor beam: something that exerts forces at a distance and lets us pick things up without touching them. Luckily, tractor beams exist! Let's think of a couple of ways we could build one.

Sonic Tractor Beams

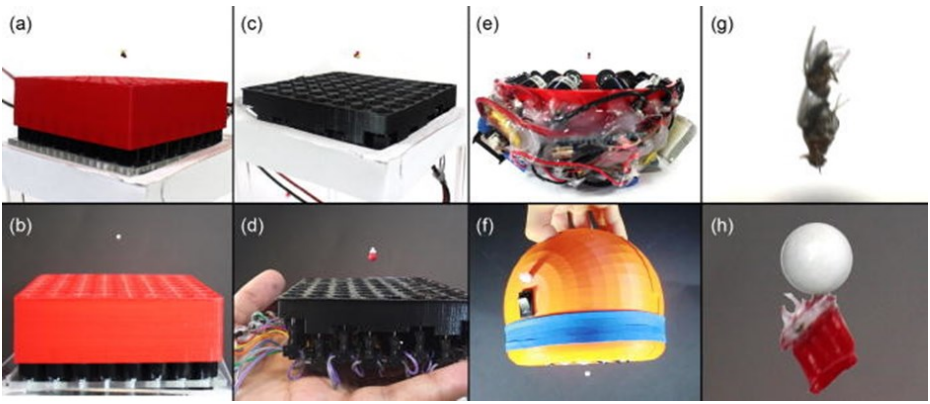


Figure 2: *Sonic tractor beams and their victims. Note the two fruit flies being levitated!*

Small objects, perhaps a millimetre or so across, can be levitated using sound waves. This is called a sonic tractor beam. Figure 2 shows some examples of tractor beam designs, and the objects they have lifted:

To prove that this is possible, our group will demonstrate a working sonic tractor beam (pictured below). The device relies on interfering many sound waves together (coming from the many black transducers in the picture). Since sound waves change the pressure of air that they're moving through, interfering them in the right way can create regions of low pressure that suck small objects in without damaging them.

Figure 3: *Our sonic tractor beam. Each black transducer is a source of sound waves.*

Optical tweezers

Sound waves still won't do for the very smallest objects, like cells or atoms. For these we need to turn to a different type of wave: light. In biology, tools called optical tweezers can be used to manipulate single cells, or even single DNA molecules:

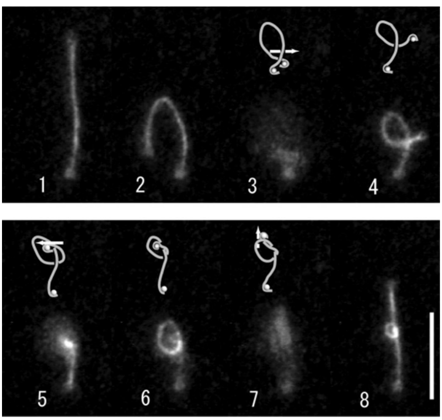


Figure 4:
A single DNA molecule being tied into a knot. Both ends are being held by optical tweezers, the only tools precise enough to perform this trick.

To build optical tweezers you need to take a laser beam and focus it down to a very narrow radius. Very tiny objects will feel an attraction to the narrowest point, if you choose the frequency of the laser beam correctly:

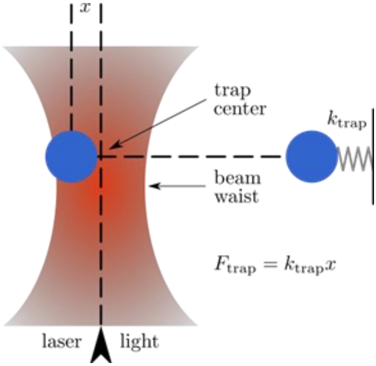


Figure 5:
Optical tweezers. Around the narrow focus of a laser beam, very tiny objects feel a spring-like restoring force pulling them to the region with the most intense light.

Light and atoms

We use a similar principle in our group to manipulate atoms. Light interacts with atoms in different ways depending on how intense it is and what frequency it has, making it a wonderfully versatile tool that can heat atoms, cool them, attract them, repel them, excite them, or de-excite them. Lasers are the best way to direct light exactly where we want it and make sure its frequency and intensity are correct.

When a laser beam shines onto an atom, we can think of the atom seeing a stream of photons, all identical and all heading in the same direction. The atom can absorb a photon and be promoted to a higher energy state, but it won't stay in that higher state forever: at some point it has to lose the photon again. This can happen in one of two ways, and that's the key to using light to control atoms.

The first way is *spontaneous emission*. This is when the atom just emits the photon in a random direction, and the photon doesn't re-join the laser beam. The atom is kicked around at random as more photons bump into it.

The second way is *stimulated emission*. This is a much stranger quantum process where the atom emits the photon back into the laser beam, as if it never left. While this might seem as though it makes no difference to the atom, quantum mechanics dictates that this must shift the energy of the atom up or down depending on the frequency of the laser.

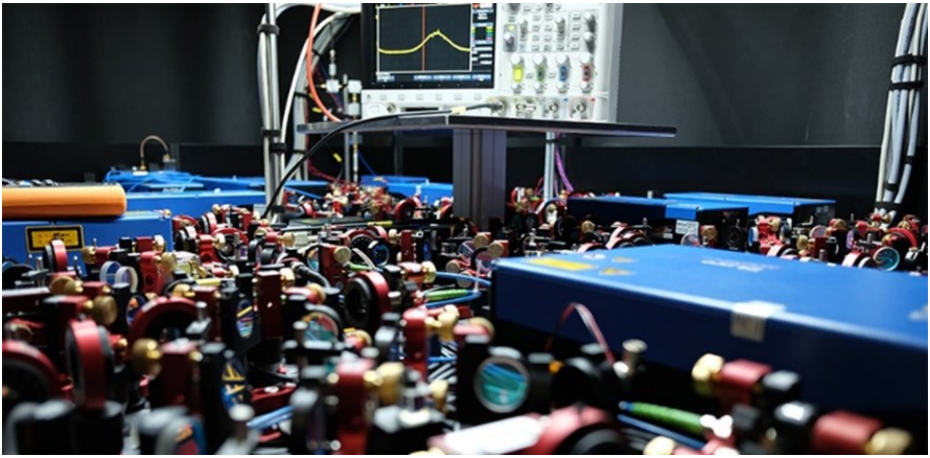


***Figure 6:** Some of the lasers and optical equipment we use for trapping atoms.*

The atom always wants to enter the region where it has the least energy, so it feels a force pushing it either into or out of the laser beam. We call this force the optical dipole force, and we can use it to make optical tweezers for atoms. This device is called an optical dipole trap, and often we use two laser beams at right angles to confine the atoms to the region where the beams overlap.

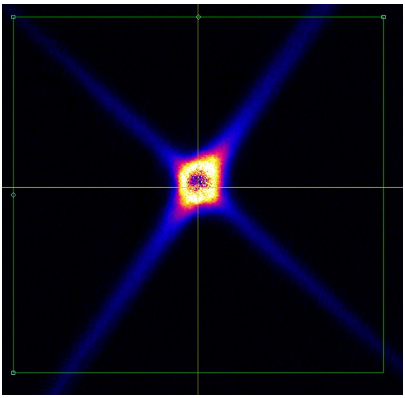


Figure 7:
A cloud of rubidium atoms in our apparatus, trapped in our optical dipole trap. (False colour.)

Our group

We work with clouds of rubidium and potassium atoms that we cool (using lasers) to extremely low temperatures (less than 100 nK). At these temperatures quantum uncertainty makes each atom bigger than the distance between two atoms, so that the whole cloud becomes quantum, and this leads to very interesting behaviour. We are particularly interested in loading these clouds into optical lattices, which are patterns made by interfering laser beams. The pattern we choose makes a big difference to the behaviour of the cloud, so if we make a pattern similar to the arrangement of atoms inside a solid we can learn something about that solid's properties.

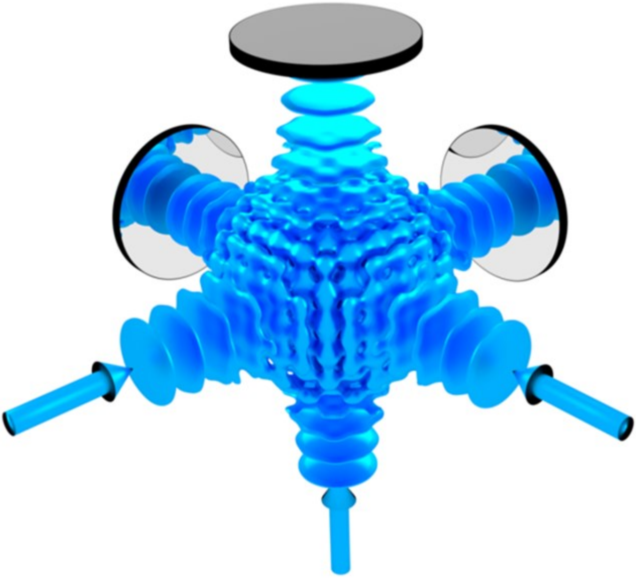


Figure 8:
Diagram of an optical lattice. The complicated structure of peaks and troughs arises from interference between laser beams, reflected by mirrors.

Image Credits

Tweezers:
Zephyris at the English language Wikipedia [GFDL (http://www.gnu.org/copyleft/fdl.html) or CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0/)], via Wikimedia Commons

Sonic levitation examples:
A Marzo et al, Realization of compact tractor beams using acoustic delay-lines, Applied Physics Letters, Volume 110, Issue 1 (2017)

Tying DNA in knots:
Arai, Y. et al., Nature 399, 466-468 (1999)

Optical tweezer diagram:
By Locke83 (Own work) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons

21. Eight19

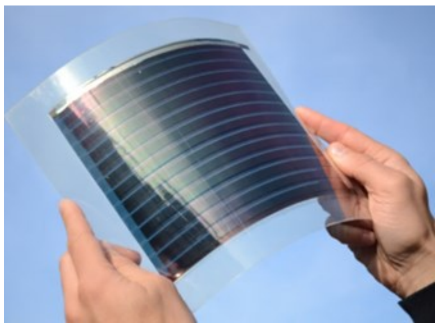
http://www.eight19.com

Eight19 is a small start-up company that is only 6 years old. We do research into and manufacture a new type of solar technology called organic photovoltaics. Organic photovoltaics are one of those things that sound complicated but actually describe exactly what they are if you look closely enough:

- Organic – this means primarily made of the elements carbon and hydrogen. Plus maybe some nitrogen and sulphur. Petrol is a classic example of an organic material.
- Photo – light!
- Voltaic – to do with electric current

Organic photovoltaics is therefore using materials primarily made of carbon and hydrogen, to make an electric current, from light.

Solar Technology



Organic photovoltaics are just one player in the field of solar technology. In 2015 1.5% of the UK's electricity came from solar power and more than 80% of the British public supported solar power, making it the most popular source of power[1]. The solar panels you see on roofs and in fields have an efficiency of 17% on average, but there is the potential for this efficiency to increase beyond 20%.

What's great about using organic materials instead of the traditional ones like silicon, is that they are light weight and flexible. We can manufacture our solar modules on pieces of flexible plastic and roll them up around a core (like a very high

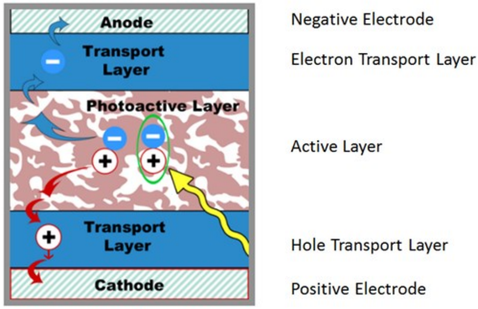
1. Solar Trade Association, 2015

tech loo roll…). This means that we can transport them really easily and that in the future they could be part of building designs.

The other big advantage of using organic materials in that they can be used to produce electricity indoors. The materials we use absorbs the wavelengths of light that correspond to fluorescent lighting (the type of lighting used indoors in places like supermarkets and schools) so will still work when you take them indoors.

Coatings

Our solar modules are made by coating and drying solutions one by one on top of each other to make up a stack. For example you have to start with a bottom electrode, then have other conductive materials and the active layer (the bit that absorbs light) and a top electrode. There is a lot of science related with getting the coatings right – if your coating is bad then the solid in it might not crystallise well and it won't work at all! Things to consider include the viscosity (thickness) of your solution and the properties of the material you're trying to coat it on to. If your solution isn't thick enough it will just run everywhere, if it's repelled by what you're coating it on then you'll get what are called dewets (holes in the coating – not good!) At the physics at work exhibition you're going to have a go at improving some coatings.



Plastic Solar Cell Cross Section

Name: Martyn Rush
Position: Scientist
Education/Qualifications: A-levels: chemistry, maths, physics
Degree: chemistry – BSc Hons, university of Leeds, UK
Previous job history: Chief chemist at Owlstone Ltd; a chemical sensor company started from Cambridge University
Explosive detection technician at Dstl – government defence science laboratory
Other careers considered: Music producer
My day at work involves: Trying to make organic photovoltaic devices work better, reading technical/academic papers, problem solving issues with OPV devices and assisting others in the lab
The best thing about my job: Working with others and problem solving together.
Thing I like least about my job: Results that refuse to be repeated!!
Other interests: Playing the drums

Name: John Fyson
Position: Semi-retired but part time consultant to Eight19 and visiting Associate Professor at Brunel University mostly working in the Design School
Education/Qualifications: A levels in Chemistry, Physics, Pure Maths and Applied Maths. BSc (Hons) in Chemistry from University of Manchester
Previous job history: Physical Chemist and Inventor at Kodak Limited and European Research after leaving university. Most of early time there was measuring reaction rates of chemical processes taking place during the processing of photographic film and paper. This led to the formulation of improved processing chemicals and when combined with changes in processing machines, allowed faster and more environmentally friendly processing. Later, when people stopped using film, I worked on making semiconductors and other devices using atomic layer deposition.
Other vacation jobs that have been useful experience include: carpenter on a building site (I can make things), working in injection moulding foundries (the expertise of my official department in Brunel is processing plastics, which includes injection moulding – it is small world. My barman's jobs set me up as a plastic pipe plumber and pipe cleaner as well as a little knowledge of alcoholic beverages!)
Other careers considered: Working in paper and pharmaceutical research
My day at work involves: Giving chemistry and statistics advice to Eight19, a solar energy research company. At Brunel, giving advice to postgraduates on electrochemistry and supercapacitors as well as helping 3rd year undergraduate student complete their projects so that their usually good ideas are reduced to practise.
The best thing about my job: Learning new things, anything, through playing, watching and reading, and passing anything useful (and probably not so useful) on to others. Meeting new people and seeing new things
Thing I like least about my job: Very little - repetitive things and sorting out grant applications etc.
Other interests: Photography, history and I am a church warden

Name: Rebekka Willcocks
Position: Material Development Technician
Education/Qualifications: A Levels in Maths, Biology, Chemistry, and Media. Foundation degree in chemical science.
Previous job history: Waitress and hairdresser's assistant
Other careers considered: Paramedic, marine biologist
My day at work involves: Working in a team to research into flexible solar panels using chemistry, coating mini modules, and testing them, researching into new methods of production
The best thing about my job: Working in a friendly team, finding new and exciting ways to progress the technology
Thing I like least about my job: Working with smelly chemicals
Other interests: Media, biology, reading, dancing, Disney

Name: Charlotte Ferru
Position: Process development engineer
Education/Qualifications: Master degree in Physics and Chemistry from the National School of Physics, Chemistry and Biology of Bordeaux(FRANCE)
Previous job history: Eight19 is my first job. I previously did an internship at EWII in Denmark, working on fuel cells systems that would provide electricity and hot water for households
Other careers considered: Any development work in the renewable energies field
My day at work involves: Planning experiments, improving the process on a pilot Roll-to-Roll machine, analysing results and writing reports. The aim is to scale-up a process with minimal loss in performance from small scale to production scale.
The best thing about my job: Since Eight19 is a start-up, there is always something different to do! The processes are constantly evolving and I get to discover a lot of new different things
Thing I like least about my job: Since Eight19 is a start-up, there is no long term plan. Priorities, objectives etc. change often, which makes it hard for teams to keep an efficient focus
Other interests: Traveling! And I also like pandas quite a lot.

Name: Pavel Procházka
Position: Operator
Education/Qualifications: Czech equivalent of A-levels: Czech and English language, Maths and Chemistry. At University I studied chemistry in relation with sources of energy (both traditional – oil & gas and alternative) and protection of environment.
Previous job history: Couple of trainee programs during my studies and several temporary positions after I moved to the UK.
Other careers considered: Teacher, engineer in oil & gas
My day at work involves: Lifetime testing of organic photovoltaic cells and working on experiments to improve their lifetime. Processing data and preparing encapsulation material.
The best thing about my job: The variety of tasks, technical challenges, opportunity to learn new skills and gain some knowledge about area I didn't know much about before. Friendly and supportive colleagues.
Thing I like least about my job: Repetitiveness of some tasks which need to be done on a regular basis.
Other interests: Orienteering, aikido, hiking and exploring.

Name: Jurjen Winkel
Position: Technology Manager
Education/Qualifications: BSc and DPhil in Chemical Physics from Sussex University
Previous job history: Senior Scientist at Kodak Ltd, developing technologies based around silver halide materials and (electronic) display (13 years).
Other careers considered: Refuse collector (aged 5), gold extractor (aged 10), Business builder (aged 13), geneticist (aged 15), Scientist (aged 22) – i.e. not always easy to know what you want at an early age!
My day at work involves: Managing technical projects, liaising with collaborators from industry and academia, managing and maintaining company Intellectual Property, Health and Safety Officer.
The best thing about my job: Being involved with cutting edge science and technology, finding creative ways to use materials in novel ways to achieve the company's goals and working with clever and creative people.
Thing I like least about my job: Admin, especially when related to health and safety, but it is a vital part of any company
Other interests: Squash, Cycling, the great outdoors (especially hills, forests, coasts and ancient ruins)

Name: Gabriel Ogien
Position: Research Engineer
Education/Qualifications: Scientific high school in France then Master in Chemistry and Physics at ESPCI ParisTech, a French engineering school
Previous job history: During my education, I did an internship in Cambridge for Plastic Logic, a start-up company that develops flexible screens, working in the lab. I did another internship for EDF, the main French energy company, to screen patents on intelligent electric grids. After graduating I went to work for a French start-up on flexible solar panels, and then moved to Cambridge to work at Eight19 to work on similar topics.
Other careers considered: Forensic scientist, historian, archaeologist
My day at work involves: A lot of surprises! It really depends on the day and it can go from carrying heavy rolls or explosive gas bottles to reading theoretical papers about quantum physics or fixing a robot.
Mostly though, it implies protecting our solar panels by encapsulating them in between two flexible barriers and testing them to see how fast they degrade. The main job is to improve that process, find new materials, as well as finding a way to predict their lifetime and new ways to characterise them faster. About half of it is lab work, and the other half is data processing and analysis, and sometimes I do some programming to automate measurements.
The best thing about my job: Working with a suicidal robot. Definitely.
Also, it's very diverse, each week is different from the previous one and I keep learning about new things. It's a good compromise between being in the lab and in the office (you can go in the lab when you get bored of the computer and vice versa). Also, it is a collective job and I'm working with a team of great people, which is really nice.
Thing I like least about my job: Some repetitive tasks involving sample preparation/measurements.
Other interests: Travelling, history, experimental cooking, origami

Name: Chloe Francis
Position: Material and Device Scientist
Education/Qualifications: I took the International Baccalaureate instead of A-levels – higher level Chemistry, Biology, French, standard level Maths, English, History. Integrated masters in Chemistry (MChem) at the University of York and Heidelberg University (Germany).
Previous job history: Waitress/housekeeper, Ecotoxicologist
Other careers considered: Ecotoxicology
My day at work involves: Planning and running experiments to test the efficiency and stability of our solar cells. Trying to come up with ways to make them more stable. Reporting the results and helping my colleagues with testing and manufacturing our solar cells.
The best thing about my job: Getting in to long discussions with my colleagues about our work and interesting new ideas.
Thing I like least about my job: When our office is freezing!
Other interests: Dancing, travelling, languages, baking

22. Domino. Do more.

http://www.domino-printing.com

What Does Domino Do?

Domino use a printing process called continuous ink-jet printing to mark and label a vast range of products, varying from the eggs you eat for breakfast, to the numbers printed on your winning scratch card. Virtually everything manufactured today had been coded, labelled or marked before reaching you – the consumer.

The History of Domino...

Domino was founded in Cambridge in 1978. Not long afterwards EU legislation was introduced requiring all food products to be marked with a best before date. Continuous ink-jet printing provided a perfect solution, as it is fast and doesn't involve contact between the printer and the product.

So What is Continuous Ink-jet Printing?

Continuous ink-jet printing involves the jetting of ink onto a surface without being in contact with it. The main advantage of continuous ink-jet printing is the speed: a single nozzle can generate up to 150,000 drops per second, which allows the surface being printed to travel over 10 mph (up to 5 m/s).

Continuous inkjet printing is different to the drop on demand ink-jet printing used in your desktop printer. Drop on demand printing has hundreds or thousands of nozzles in a line, which each print a single drop when the nozzle is triggered. However the continuous ink-jet printing used by Domino only uses a single nozzle, which is continuously forming drops. Ink is constantly being jetted through a nozzle, which is about the same width as a human hair.

If you squirt water through a hosepipe the jet will eventually break-up into drops; this is because the jet becomes unstable due to natural pressure fluctuations. A similar technique is used in continuous ink-jet printing; by introducing a controlled vibration within the jet, the stream of ink can be made to break-up into regularly sized drops.

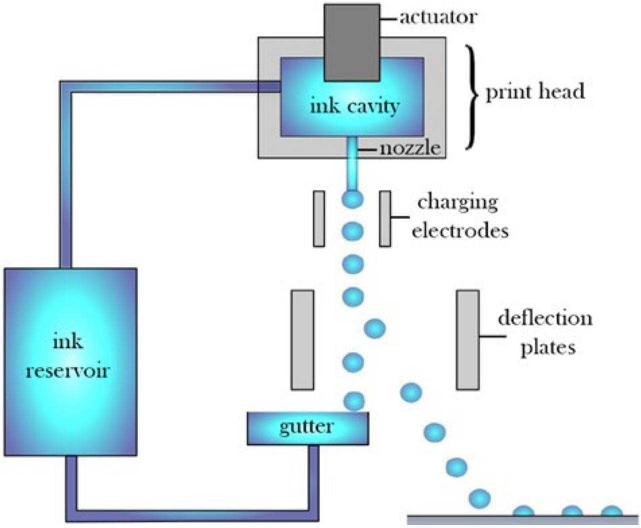


Figure 1: *A simple example of a continuous ink-jet print system*

Figure 1 shows the basics of how a continuous inkjet printer works. Ink in the ink cavity is jetted through the nozzle. A vibration is introduced by an actuator behind the nozzle - this makes the jet break into drops. The drops then pass through a charging electrode, which causes the drops to become charged as they pass through it. The charged drops then pass through deflection plates. One is held at a negative voltage and one is kept positive, creating an electric field between the two plates.

As a charged drop passes through the electric field it is attracted to the deflection plate with the opposite charge, and repelled by the plate with the same charge. The electrostatic force causes the drop to change direction as it passes through the deflection plates. The change in direction is used to steer the drops onto the surface of the product being printed.

If a drop doesn't need to be printed the charging electrode does not charge the drop, so it is not deflected and travels straight down and lands in the gutter. The unused drops are then recycled and printed again. In order to get a complex pattern the charging electrode charges some drops more than others. Drops with more charge will deflect further so a larger area can be printed.

And the future?

Domino does not just print on products, they also print the boxes the products are put in, and even on the pallets the boxes are loaded on.

Domino does not only sell continuous ink-jet printers, but has a range of products including full colour drop-on-demand label printers, laser scribing and thermal transfer printers.

So next time you go to the supermarket, have a look at how many items have probably been printed using a Domino print-head!