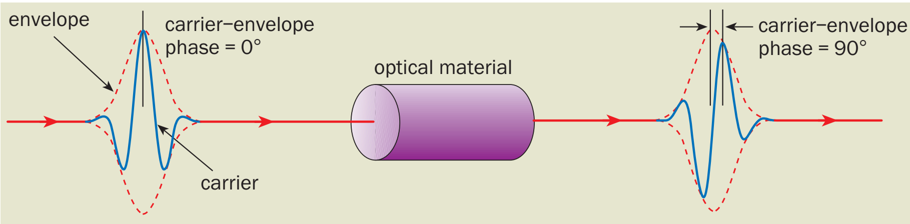


1 The carrier wave (blue) and envelope (red) of a light pulse move at different speeds in an optical material. These can be out of phase by an amount known as the carrier–envelope phase.

a smooth spectrum in the cut-off region, which is the signature of a single collision of maximum energy that gives rise to a single burst of cut-off photons. When they changed the CE phase to 90°, they measured a strongly modulated cut-off spectrum. This is evidence for two temporally separate bursts of photons, which produced an interference pattern similar to the fringes seen in a Young's double-slit pattern. In fact, the experimental data were so clear that the researchers could use this collision process as a "detector" to determine the absolute CE phase. When they switched off the stabilization of the phase, the features in the spectrum became washed out because of the random fluctuations of the electric-field waveform from one laser pulse to the next.

The importance of this result is that physicists can now control precisely when the ionization and collision of an electron from an atom or molecule will occur using intense few-cycle light pulses. A full description of this process requires the electron to be defined in terms of its wavefunction, which is subject to quantum-mechanical uncertainty. However, with ultrafast light pulses that have their CE phases stabilized, we can now control the motion of the electron down to an unprecedented limit – that set by the uncertainty principle.

Researchers are planning to use the bursts of attosecond radiation emitted at precisely defined times to make measurements of extremely fast processes that have not been accessible until now. These include the electronic changes that determine how matter is bound together, and how physical and chemical changes occur. This is a fundamental level of control, and these developments are therefore very exciting.

Astrophysics and air travel

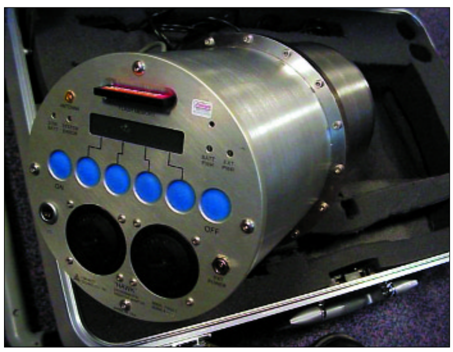
A proportional counter that mimics human tissue can measure cosmic-radiation exposure at high altitudes

From **Graeme Taylor** at the National Physical Laboratory, Teddington, UK

If you have a fear of flying, then probably the last thing on your mind when you are 10 km above the ground is what might be going on in the depths of the galaxy. But airline pilots and cabin crew might want to brush up on their astrophysics. High-energy particles coming from violent galactic events mean that radiation exposure for aircrew is higher than it is for most people classified as radiation workers. But the type of radiation that they are exposed to is very different.

The majority of the exposure comes from cosmic radiation that originates outside our solar system. Violent events such as stellar flares, supernovae and the explosion of galactic nuclei produce a concoction of subatomic particles, primarily protons and electrons. The energies of these particles can be greater than 10^{20} eV – billions of times higher than in the most powerful particle accelerators – although such energetic particles are very rare. Nuclear particles, which comprise about 98% of the radiation, typically have energies that are between 100 MeV and 10 GeV per nucleon.

On the surface of the Earth the atmosphere shields us from almost all of this radiation, but at the altitudes at which aircraft fly the levels of radiation are about 150 times higher – and the aircraft itself offers no protection. The impact of the galactic radiation on molecules in the upper atmosphere results in the generation of neutrons from nuclear interactions and electrons from electromagnetic cascades. It is these two particles that are the dominant sources of exposure for aircrews, in roughly equal measure (see "Cosmic rays: an in-flight hazard?" by Denis O'Sullivan *Physics World* May 2000 pp21–22).



High flyer – it may not be on everyone's packing list, but the tissue-equivalent proportional counter is an important device for measuring the exposure to cosmic radiation when flying.

Plastic tissue

In 1999 the neutron metrology group at the National Physical Laboratory in the UK was contacted by the Civil Aviation Authority to ask if we had any instrumentation that would be suitable for measuring the radiation exposure of aircrew. By coincidence, we were in the process of evaluating just such an instrument for a company called Far West Technology in California. The instrument in question was a tissue-equivalent proportional counter (TEPC) that was bundled with prototype electronics. The whole system fitted into a small suitcase and was battery powered, which meant that it could be left onboard an aircraft for several days at a time to measure the radiation doses on particular routes.

The TEPC is based on a spherical proportional counter. A thin outer casing of aluminium holds a spherical shell made from conducting plastic that is about 0.2 cm thick and encloses a gas cavity approximately 12.5 cm in diameter. The plastic is a special combination of polythene, nylon, graphite and calcium fluoride, which are mixed in such a way that the overall composition is similar to that of human soft tissue. It is the presence of the graphite that gives the plastic its conducting qualities, albeit very poor ones. The filling gas used is propane, which has a composition similar to that of tissue.

It is here that the operation of the TEPC starts to deviate from a more orthodox proportional counter. Traditional counters tend to be filled to pressures of one or more atmospheres, but the TEPC is only filled to about 0.01 atmospheres. This means that most of the events detected originate in the plastic wall rather than the gas, and also that the majority of the particles cross the entire counter rather than stopping.

The tissue equivalence of the TEPC means that when cosmic radiation interacts with it, the reactions are similar to those that would be produced in living tissue. This alone means that the TEPC gives a reasonable measurement of the absorbed radiation dose. In addition the ionization that is produced by charged particles that cross the counter is equivalent to the amount that would be produced in a volume of tissue smaller than a human cell. This is sufficiently small that the counter effectively samples the rate at which a particle deposits energy, which can be related to how damaging the particle is to tissue – normally called the particle's radiation quality.

By combining the measurement of the absorbed dose with the derived value for the radiation quality, a value for the dose equivalent in sieverts can be calculated. The upshot of this rather convoluted process is that the TEPC response is closely related to the amount of tissue damage caused by exposure to radiation, particularly for those particles and energies found in cosmic-radiation fields at high altitude.

In practice there are many complications to this rather simplified approach, such as the assumption that the TEPC is fully tissue equivalent, which is not valid at all energies. As a result, the TEPC is calibrated in terms of dose-equivalent response in the simulated-cosmic-ray facility at CERN. Nevertheless, the TEPC is generally considered to be the best instrument for performing cosmic-ray dosimetry in aircraft.

By the end of 1999 a collaboration had been established between the National Physical Laboratory, the Civil Aviation Authority, the Mullard Space Science Laboratory and Virgin Atlantic Airways to perform dose measurements on airline routes with TEPCs. These began in early 2000 and are still ongoing. By the end of last year the collaboration had used five TEPCs to measure doses on over 500 flights. These flights were mostly on Virgin Atlantic commercial routes from London to destinations in South Africa, the US, Europe and the Far East. Several groups are also using these data to validate computer models of dose rates, and recently the European Commission's DOSMAX group, which has been performing measurements with a variety of different devices, has offered to accept these additional TEPC measurement data.

The collaboration has also been investigating possible correlations between doses and unusual solar activity – generally known as space-weather effects (see "Space weather: physics and forecasts" by Janet Luhmann *Physics World* July 2000 pp31–36). So far the only space-weather effects observed have been the daily modulation caused by the Sun's activity. Measurements of radiation dose have been made during two significant solar flares but no elevated doses were recorded at flight altitudes. It is known, however, that some flares do lead to elevated doses at altitude, and it is the tell-tale signs in the build up to such flares that we are trying to identify.

With another two years to run on the project, it may be possible to reach 1000 flights in total. Furthermore, although the probability of observing a major solar event is small in the current phase of the solar cycle, it is still a possibility. But regardless of any interesting solar activity, a self-consistent database of doses and aircraft routes will enable us to validate predictive computer models more precisely.

Exploding excited electron bubbles

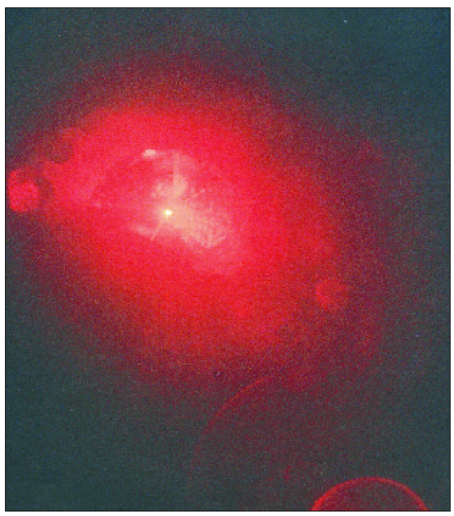
First observations of excited electron bubbles in superfluid helium reveal puzzling features

From **Peter McClintock** in the Department of Physics, Lancaster University, UK

The "particle in a box" is a standard second-year quantum-mechanics problem, much beloved by lecturers and mastered (or not) by successive generations of undergraduates. An electron bubble in liquid helium provides a strikingly simple example of this kind of system, and theory predicts that it should exhibit a series of excited states. But these states have never been demonstrated experimentally. Now Denis Konstantinov and Humphrey Maris of Brown University in the US have observed one of these excited states for the first time by exploding electrons bubbles with sound waves (D Konstantinov and H Maris 2003 *Phys. Rev. Lett.* **90** 025302).

When an electron is placed in liquid helium, it expels about 1000 helium atoms from around itself and creates a vacuum bubble that contains nothing but its wavefunction. The size of the bubble is determined by the interplay of various energy contributions. Larger bubbles reduce the zero-point energy of the electron – the minimum energy that it can have due to quantum-mechanical uncertainty – but at the same time they have a greater surface energy than smaller bubbles. If there is a finite ambient pressure then the volume energy of the bubble will also increase.

There is therefore an optimal bubble size that minimizes the total energy. When the electron is in its 1s ground state, the resultant bubble is spherical with a radius of 1.9 nm for zero applied pressure. With its negative electronic charge, the bubble is a semi-macroscopic object that is often somewhat misleadingly called a negative ion.



Exciting stuff – electron bubbles can be exploded to giant sizes that enable them to be detected with a He–Ne laser.

Blowing bubbles

Electron bubbles have proved to be exceedingly useful probes of superfluid helium-4, which is otherwise hard to study because it is inert. They can be formed easily by injecting electrons into the liquid helium using a sharp metal tip, and their subsequent arrival at any point in the apparatus can be registered as a current. Electron bubbles have been used for several important experiments on superfluid helium-4, such as a measurement of the Landau critical velocity at which superfluidity breaks down, and for studying the creation and decay of quantized vortices and superfluid turbulence.

These experiments use ground-state electron bubbles, in which the trapped electron is in its 1s state. But electron bubbles also have excited states. Here the average radius and shape of the bubble will be different because the internal pressure and symmetry of the electron wavefunction will not be the same.

Calculations of the form of the bubble for different applied pressures – also made by the Brown group – yield interesting results for the 1s and 1p states (see figure 1). With positive applied pressure, the vacuum–helium interface that "dresses" the electron is pressed tightly around it, and the shape of the wavefunction impresses itself strongly on the bubble. This is clearly seen for the 1p state at a pressure of 5 bar. But as the pressure is reduced the bubble grows and loses its "waist".

Until now it has been far from clear how any of these phenomena might be demonstrated experimentally. Maris and Konsantinov applied a strong acoustic field to the bubbles and measured the negative pressures at which they became unstable. They operated an ultrasonic transducer at 1.4 MHz, which produces waves with a period that is longer than the few picoseconds that it takes for the bubble to equilibrate. The bubble therefore perceives the acoustic field as a quasi-static change in the ambient pressure.

Their calculations show that there is a critical reduced pressure at which the growing bubble becomes unstable and explodes because the surface tension is no longer capable of holding it together. The critical pressures are calculated as –1.89 bar for the 1s bubbles and –1.63 bar for the 1p bubbles.