OCR
RECOGNISING ACHIEVEMENT

Friday 27 January 2012 – Afternoon

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495 Field and Particle Pictures

INSERT

Duration: 2 hours

INSTRUCTIONS TO CANDIDATES

- This Insert contains the article required to answer the questions in Section C.

INFORMATION FOR CANDIDATES

- This document consists of **8** pages. Any blank pages are indicated.

INSTRUCTION TO EXAMS OFFICER/INVIGILATOR

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Floating an idea or two

Every day, across the world, hundreds of balloons are released into the air to enable scientists to make a range of studies of our atmosphere. Some of these balloons are used in a simple way to measure the altitude of the bases of clouds. These so-called 'ceiling balloons' are boldly coloured (usually red) and small. After being released, they are observed continuously (the use of binoculars is usually sufficient) and the time taken for them to disappear into the cloud is measured.

Many other much larger balloons carry atmospheric monitoring equipment (typically of mass 0.25 kg) to very high altitudes. These can measure a range of parameters including temperature, humidity and pressure. The measurements are transmitted to ground-based detectors across the world and Global Positioning Systems (GPS) can be used to track the positions of the balloons, enabling wind speeds and directions to be determined as well. Data collected in this way are brought together in a global collaborative project to enable a detailed analysis of the Earth's atmosphere to be made on a daily basis.

Fig. 1: a helium-filled weather balloon shortly after being released

Weather balloons are made of a very flexible rubber-based material and have a mass of about a kilogram before being inflated. They are usually filled with hydrogen, though sometimes helium is used. The roughly spherical balloons are typically about 2 m in diameter. Upthrust (see Box 1) causes them to rise and as they do so they expand; at altitudes of around 35 km, their diameters have increased to about 8 m. When they exceed this size, they burst and the small package of measuring instrumentation (called a 'radiosonde') falls to the Earth's surface. A small parachute automatically deploys to reduce the risk of harm when it lands and to preserve the instruments so that they can be re-used.

Box 1 – The Upthrust Force

When an object is immersed in a fluid, it will displace its own volume of that fluid. As a result, it will experience an upwards force (the buoyancy or upthrust) equal to the weight of the amount of fluid displaced. For example, a 1 cm × 1 cm × 1 cm cube of iron will displace one cubic centimetre of water when placed in a beaker of that water. The weight of 1 cm^3 of water is about 0.01 N, so that the upthrust force on the iron cube is 0.01 N. Since the weight of the iron cube itself is about 0.08 N, it will sink when placed in the water. Weather balloons, however, have a weight less than that of the volume of fluid they displace (air). The net force, and thus acceleration, is upwards so they rise.

Balloons have not just led to studies of the Earth's atmosphere. Similar balloons have been used to enable other scientific measurements to be taken at high altitudes, of other features of the Earth and of the universe beyond.

Pictures from the edge of Space

In February 2009, four Spanish schoolboys (of the Meteotek project) astounded scientists when they took pictures of the Earth's atmosphere using a simple digital camera that had been carried over 30 km into the sky by a helium-filled weather balloon. This type of low-budget experiment was undertaken by several other groups across the world shortly after.

Fig. 2: photograph taken by the Meteotek Team using a digital camera in their high-altitude balloon

The sample photograph in Fig. 2 shows cloud formations in the stratosphere and the curvature of the Earth is clearly visible. This picture was taken just a few weeks after NASA had announced details of a prototype balloon that could carry up to a tonne of equipment to great heights (over 35 km) and for sustained periods of time (11 days or more). There are long term plans for such balloons to replace satellites for certain functions as they are cheaper and more accessible. Mapping and monitoring the surface of the Earth would be a principal function and relatively easily carried out at a range of altitudes. The image in Fig. 3 was taken with a similar camera to that used for Fig. 2, with a screen resolution of 4352 × 3264 pixels.

Fig. 3: digital camera image from a balloon at an altitude of just over 1000 m

Cosmic ray studies

Cosmic rays were discovered using measurements taken in a balloon by the scientist Victor Hess in 1912. He discovered that their incidence increased with altitude and proposed that they were of a cosmic origin. He was awarded the Nobel Prize for Physics in 1936 for this discovery.

Cosmic rays are high energy ionised particles, mostly ions of hydrogen (i.e. protons) which comprise about 90% of those detected. Helium ions make up about 9% whilst the remainder is a mixture of other familiar ions (including carbon and oxygen). Some cosmic ray particles originate from the Sun and these have relatively low energy (no more than about 10 MeV) but the majority are much higher energy (hundreds of GeV) and are believed to originate largely in exploding stars (supernovae).

The cosmic rays can be detected at high altitude towards the very top of the atmosphere which can be accessed by some weather balloons. Early measurements were made using photographic plates. When the cosmic ray particles struck an atom in the photographic emulsion, new particles were created and from the tracks they produced in the film, the nature of the cosmic ray could be established.

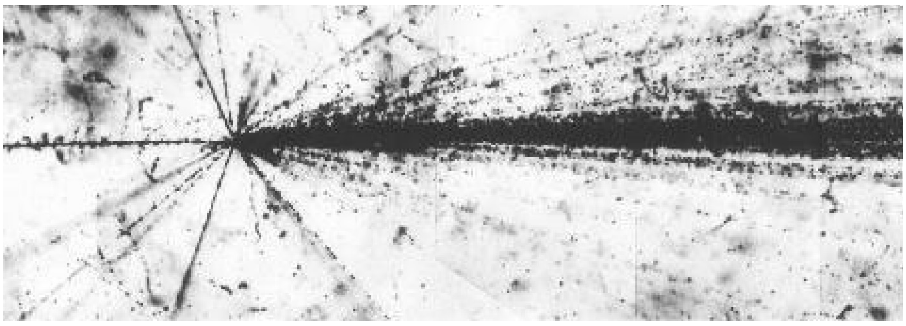

Fig. 4: a developed photographic film showing particle tracks

The atmosphere shields the surface of the Earth from the cosmic rays and is equivalent to a layer of concrete about 4 m thick in this respect. Thus, at ground level or in the lower atmosphere, only the products of the cosmic ray interactions with upper atmosphere particles can be detected. Such interactions produce a shower of new particles followed by a cascade of other particles down to the Earth's surface. These new particles are mostly unstable mesons with very short half-lives. However, because they travel at speeds near to the speed of light, relativistic time-dilation ensures that a significant number can still reach the surface of the Earth.

Cosmic Microwave Background Radiation

Perhaps one of the most high-profile and successful projects undertaken in a balloon was BOOMERANG (Balloon Observations of Millimetric Extragalactic Radiation and Geophysics). This comprised a pair of high-altitude balloon flights over Antarctica in 1998 and 2003. Very sensitive instruments mapped the sky to build up pictures showing the temperature distribution of the early universe (when it was only a few hundred thousand years old) (Fig. 5). This work supported that of NASA's famous COBE satellite (the Cosmic Background Explorer). Both found that the microwave background, as measured by its temperature, is extremely uniform. However, if the early universe were perfectly uniform in temperature and density, there is no way that the present non-uniform universe, clumped by gravity into stars and galaxies, could have formed. Very small fluctuations in temperature and density of the early universe are predicted by quantum theory. Surveys of the microwave background radiation looked to see if these fluctuations existed and whether they could account for the clumping of matter into galaxies. These and other results have also led to questions about what most of the universe is made of, one of the greatest puzzles in current cosmology.

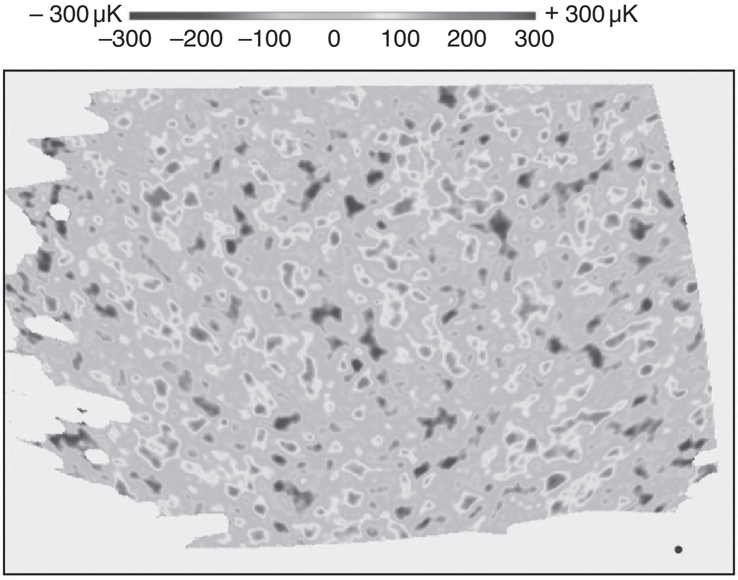

Fig. 5: map of the sky compiled by the BOOMERANG project showing temperature fluctuations in the early universe

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