Tuesday 28 June 2016 – Morning

A2 GCE PHYSICS B (ADVANCING PHYSICS)

G495/01 Field and Particle Pictures

INSERT

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Electricity for Spacecraft

One of the biggest challenges to meet when designing an artificial satellite or spacecraft is that of the on-board electrical power supply. Two major considerations are mass and lifetime, both of which depend upon the function of the craft being constructed. Batteries are usefully described by the number of watt-hours they have per unit mass (a watt-hour being the energy transferred by a one watt device in one hour). Typically, these days, several kilowatts of power are required and the supply needs to function reliably in extremely hostile conditions.

The power supply for the very first artificial satellite, Sputnik 1, used batteries that lasted for twenty-two days. Modern craft have greater power demands and need to last for much longer. Therefore, rechargeable batteries are employed with solar panels being used for the re-charging process. For spacecraft travelling particularly large distances from the Sun, solar cells have limited use and another means of electrical generation is required. This uses the thermal energy produced from radioactive decay to generate electricity.

Catching the Sun

For satellites and space probes based in the inner Solar System, solar panels are the most common generators of electricity. They consist of large arrays of photovoltaic cells and are characterised by the amount of electrical power that can be generated per unit mass. A typical value for panels used on satellites in Earth orbit is $300\,\text{W}\,\text{kg}^{-1}$. Perhaps the most familiar set of satellite panels belongs to the Hubble Space Telescope (Fig. 1) on which there are two large arrays.

Fig. 1: The Hubble Space Telescope

Each array can produce a maximum of 2.8 kW of electrical power. An orbit takes about 97 minutes but for 36 of those minutes the telescope is in the Earth's shadow and the panels do not generate electricity during these eclipse periods. For this reason, some of the electrical energy generated is stored in an on-board rechargeable battery, which can provide complete power for 7 hours.

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Solar panels become less effective with increasing distance from the Sun, since light intensity obeys an inverse square law. Until recently the orbit of Mars was the greatest distance at which solar panels had been used. However, developments have led to them being included on probes journeying to the outer Solar System, such as the Rosetta probe to a distant comet (Fig. 2).

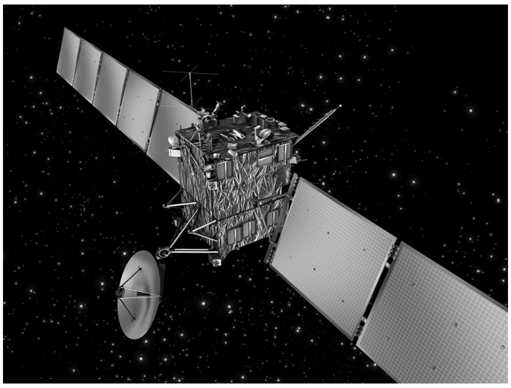

Fig. 2: The Rosetta probe, heading for a comet beyond the orbit of Jupiter

Nuclear-powered probes

For longer-lasting and more distant space missions, the principal devices used for generating electrical energy have been radioisotope thermoelectric generators (RTGs).

The first thing to note about RTGs is that they are not nuclear reactors – neither fission nor fusion plays a part. Nevertheless, there are concerns over the risks associated with such generators, especially during the launch.

Thermal energy is produced from the natural decay of the isotope, plutonium-238, which emits 5.5 MeV alpha particles. A voltage is then generated using a thermocouple. With the half-life of the isotope being 87.7 years, there is no danger of the energy "running out" and RTGs have proven to be extremely reliable. They have powered some of the most successful missions ever undertaken, such as the Voyagers of the 1980s (Fig. 3) and the more recent Cassini-Huygens probe to Saturn.

Fig. 3: Voyager 1 – one of the most successful space probes so far

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A new line of enquiry

For the last two decades, serious studies have been made of the possibility of generating voltages using Faraday's principle of electromagnetic induction. In these experiments, an orbiting satellite drags a long electrically-conducting cable through the Earth's outer magnetic field (the magnetosphere). As these 'electrodynamic tethers' cut through the magnetic field lines, a voltage is generated (Fig. 4).

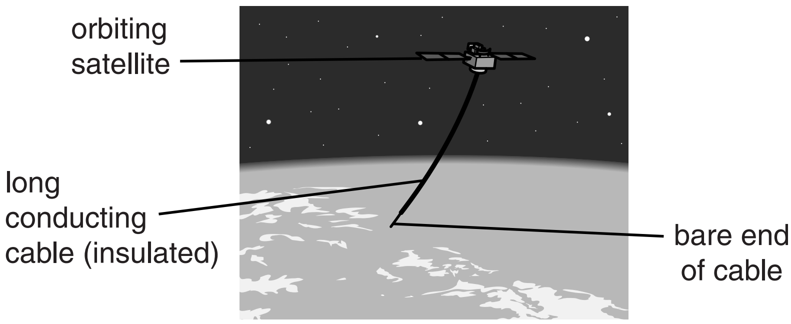

Fig. 4

Such tethers cannot be made into a complete circuit simply by adding another cable to complete the loop. However, the Earth's magnetosphere contains a large quantity of ions, created by solar radiation. There is a transfer of charge through the bare end of the cable which produces the required current. In one NASA investigation, a 20 km line was used generating a voltage of 3.5 kV. This is not a case of generating electrical energy from nothing, of course, but the method is relatively cheap and simple. This could certainly prove a lead worth following.

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