A2-2007 Q3

The Voyager 2 satellite has an 11W transmitter and beams back a signal to earth via a parabolic dish that focuses the radio waves in a diverging beam that is about 2° wide. This angular width of beam, when reaching the surface area of a sphere centred upon the satellite, corresponds to covering one ten thousandth of the surface area of the sphere. The satellite is at a distance of 10^{10} km from the earth. If it transmits at a frequency of 3×10^{10} Hz, and the energy of a photon is given by $E = hf$, then determine the maximum number of photons per second that arrive at an 80m diameter radio telescope dish on earth.

$$h = 6.6 \times 10^{-34} \text{ Js}$$

(4 marks)

AS2008 Q6

Cosmic rays are charged particles that move randomly in the galaxy as a result of being scattered by interstellar magnetic fields. The process resembles diffusion. In such situations, if a particle travels an average distance between collisions of λ (known as the mean free path) and it makes N collisions, each time going in a random direction, then the distance travelled is on average given by $R = \sqrt{N}\,\lambda$. Given the dimension of the galaxy as 5×10^{20} m and the mean free path for a cosmic ray as 3×10^{18} m, then estimate how long it takes for a cosmic ray to traverse the galaxy. Assume that it travels at the speed of light.

(4 marks)

A2-2012 Q2

The value of the acceleration due to gravity, g decreases as $\frac{1}{r^2}$ where r is the radial distance measured from the centre of the Earth (this follows from Newton's Law of Gravitation).

a) By what percentage is g less than the value of 9.81 m s^{-2} measured at the surface of the Earth, when measured at the height of a satellite orbit of 300 km above the Earth's surface?

b) What would be the value of g at the distance of the Moon (the Moon is 400,000 km away from the Earth)?

Radius of Earth = 6,400 km

(5 marks)

A2-2010 Q1(j)

A star with a diameter larger than that of the Sun can collapse to form a neutron star which has a diameter of only a few kilometres. As the core collapses to form a neutron star, its electrical conductivity becomes very high. This results in the magnetic field lines being trapped in the collapsing matter so that the field lines become denser and the field strength increases.

If the magnetic field pattern is similar to that of a bar magnet, as shown in Fig. 7 below, then as the star radius r decreases, its cross sectional area decreases, and the density of the field lines at the equator changes as $1/r^2$.

If the radius decreases from 1.4 x 10^6 km to 10 km, and the initial magnetic field strength of the star at the equator is 10^{-2} T, calculate the magnetic field strength of the neutron star at the equator.

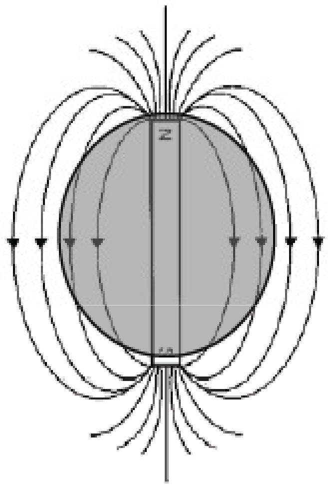

Fig. 7

(4 marks)

A2-2007 Q6

This question contains several sections that are independent of each other.

A star more massive than the sun can collapse under its own gravity to form a neutron star. Here the electrons and protons combine to form neutrons. A star which is initially rotating and collapses will rotate with a shorter period, as its rotational momentum (called angular momentum) is **conserved**. The angular momentum of the star is given by, $J=\Omega R^2$ (ignoring some constant), where R is the radius of the star and Ω is the angular rate of rotation in radians per second (2π radians is one full rotation).

a) If the volume of the star decreases by 15 orders of magnitude, and the shape of the star remains the same, then what is the ratio of the final to initial radii, $\frac{R_{final}}{R_{initial}}$?

b) If J is conserved, and $\Omega_{initial} = \frac{2\pi}{20days}$, then calculate Ω_{final} in radians/second and also the new period of rotation in seconds.

c) As the core of the star collapses to form the neutron star, the electrical conductivity becomes very high. In this case the star's magnetic field lines become frozen into the material of the star and collapse down with the star, increasing the flux density. The neutron star will thus have a very strong magnetic field. If we take the flux $\Phi=BR^2$, with B being the magnetic field strength whose initial value is 10^{-2} T, then determine the final magnetic field strength after the collapse.

d) If a neutron star spins too fast, it will start losing material from its equatorial region. Show that this implies a minimum period, T_{min} given by

$$T_{min} = const \cdot M^{-\frac{1}{2}} R^{\frac{2}{3}}$$

where $const = \frac{2\pi}{\sqrt{G}}$

Taking M=1.4 solar masses, R=10 km, then calculate T_{min} .

e) The binding energy of a neutron star is the gravitational potential energy lost when it is formed from a cloud of atoms all separated a great distance apart. The binding energy of a star of mass, M, and radius, R, is given by $BE = k_1 \frac{GM^2}{R}$, where k_1 is a numerical constant. Neutron stars do not behave in the same way as ordinary matter and they have a mass-radius relationship given by $RM^{\frac{1}{3}} = k_2$ where k_2 is a constant. Two neutron stars of identical mass collide and form a more massive star. Assuming the mass-radius constraint holds, what is the ratio of the final binding energy of the star to the total initial binding energy?

Mass of the sun = 2.0×10^{30} kg
G = 6.67×10^{-11} $\text{Nm}^2\text{kg}^{-2}$

(16 marks)

A2-2011 Q5

Johannes Kepler used Tycho Brahe's detailed observations on planetary motion, made without the use of telescopes, to determine the elliptical orbits of the planets. He also ascertained that the square of the period of orbit T is proportional to the cube of R (Kepler's Third Law). The radial distance R for a planet is the simple arithmetic average of the closest distance of approach to the Sun, R_{min} and the furthest distance from the Sun, R_{max}.

(a) Sketch a diagram of a planetary orbit, marking on it R_{min} and R_{max}.

[1]

(b) From the statement above, write down two equations, the first one relating T and R with a constant of proportionality k, and a second equation relating R, R_{min} and R_{max}.

[2]

(c) The average distance of the Earth from the Sun is defined as 1 Astronomical Unit (1 AU). Determine the value of k for part (a), including units.
(The period T can be measured in years).

[1]

(d) Halley's Comet also orbits the Sun and so the value of k is the same as in (b). Its period of orbit is 75.3 years. Determine the value of R for its orbit about the Sun.

[1]

(e) The closest distance of approach to the Sun for the comet is 0.585 AU, when it is visible to the naked eye. Calculate the furthest distance of the comet from the Sun.

[1]

(f) The comet's speed is 70.6 km s^{-1} at closest approach to the Sun. Is the speed greater or smaller than this at the comet's furthest distance from the Sun? Give a reason for your answer.

[3]

(g) As a man-made satellite orbits the Earth, there is always a point on the Earth directly below it. This point follows the path of a satellite's orbit and is plotted on a map of the Earth, as shown below in **Figure 4**. Describe or sketch the satellite's orbit i.e. how it is oriented about the Earth, and its shape.

[3]

(h) This orbit is known as a Molnya orbit and is used for some spy satellites. Apart from the obvious feature that it covers Russia and the USA, what is its advantage?

[1]

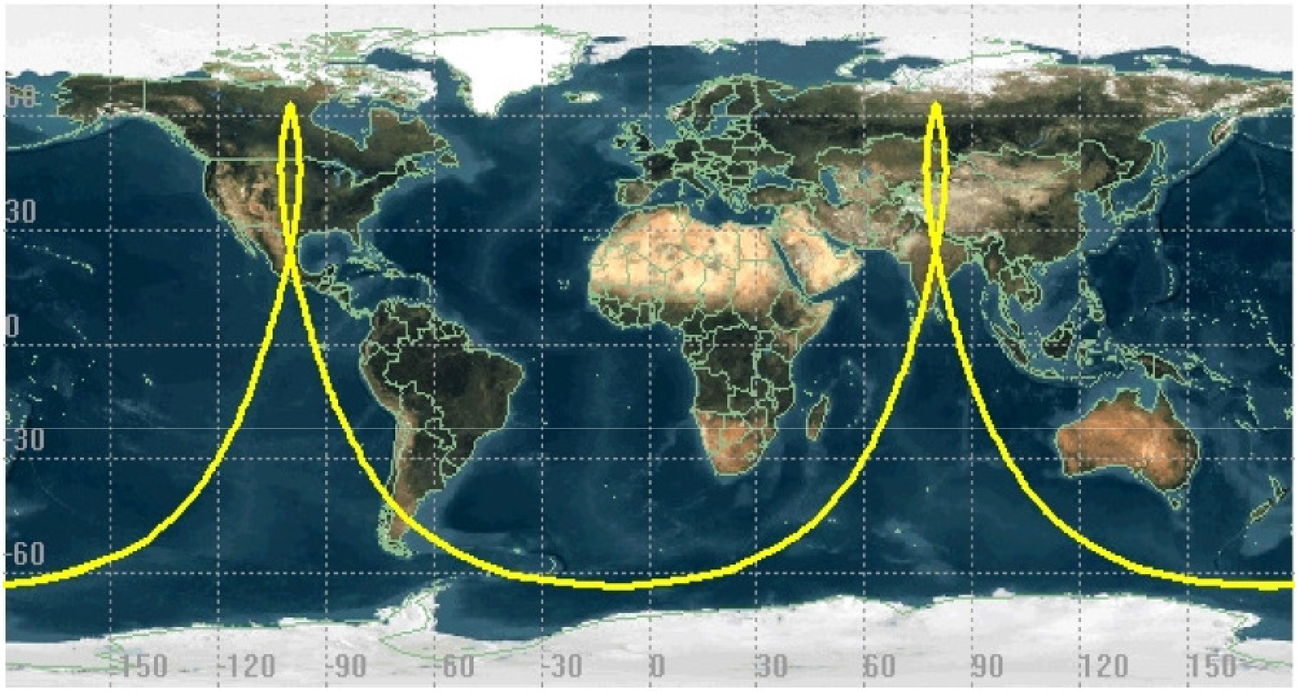

Figure 4. *Path of a satellite in a Molnya orbit around the Earth.*

(13 marks)