BRITISH PHYSICS OLYMPIAD

British Physics Olympiad 2012

A2 Challenge (previously Paper 1)

September /October 2011

Answer all questions

Allow 1 hour

Total 50 marks

$g = 9.8 \text{ m s}^{-2}$ or N kg^{-1}

$c = 3.0 \times 10^{8} \text{ m s}^{-1}$

A standard formula sheets should be made available for students

Question 1

When a satellite is launched to a distant planet, a radioisotope thermoelectric generator (RTG) is used to provide electrical power for the satellite. This consists of a decaying radioactive source producing heat which can then be converted to electrical power. NASA is allowed to launch with a maximum 25 kg mass of plutonium dioxide (PuO_2) on a single satellite, but it never uses the maximum.

a) Pu-238 itself alpha decays and NASA quotes the *specific activity* of the radioactive PuO_2 as 17 Cu/g, where 1 curie (Cu) is 3.7×10^{10} decays per second. Calculate the number of alphas released per second from 1 g of PuO_2.

b) If the plutonium emits 5.5 MeV alphas, how many watts of power per gram are released by the radioactive source? This quantity is known as the *power density*.

c) At launch, 4.5 kW of heat power are required from the source. What mass of radioactive PuO_2 is required?

d) If the conversion efficiency from thermal to electrical energy is 7%, what electrical power will this supply initially?

e) Why are solar panels not used for satellites travelling to distant planets?

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

(6 marks)

Question 2

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)

Question 3

The physicist is inevitably well prepared for travelling and packs his clothes into the idealised rolling suitcase. The empty, rectangular suitcase has a uniform mass distribution of 5 kg acting as a load at the centre of mass. In this question, the load is measured in kilograms rather than being converted into newtons. The case has a pair of wheels at corner C and a handle at corner A, as shown in the diagram below. The suitcase contents can be modelled as two point masses of 14 kg and 4 kg, of clothing and shoes respectively, located at diagonally opposite corners of the suitcase. When the handle end of the case is just raised off the ground, so that CD is horizontal, the physicist is not lifting the full 23 kg of load.

a) State or sketch on a rectangle where the load of the empty suitcase acts.

b) Fill in the right hand column of the table with the values for the load (measured in kilograms, kg) that the physicist would feel with the distributions of the masses at diagonally opposite corners. (You only need to copy down the first and final two columns of the table).

c) If instead the two masses could now be placed at **any** two corners of the case, which examples would be the two best choices and what would be the load when lifting the handle at A?

d) Of these two examples in (c), suggest which arrangement might be better if pulling the suitcase over rough ground and explain your answer.

Example	A	B	C	D	Working out	Load at handle
1	14 kg		4 kg			
2	4 kg		14 kg			
3		14 kg		4 kg		
4		4 kg		14 kg		

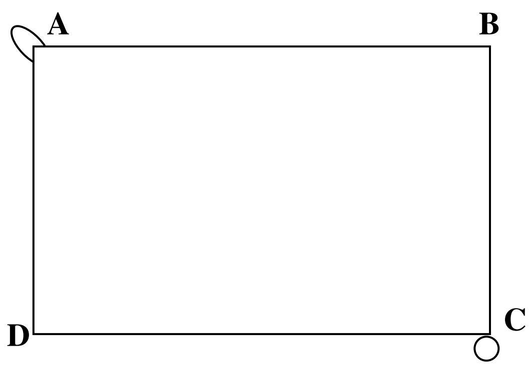


Figure 1. The physicist's ideal suitcase on wheels.

(8 marks)

Question 4

The Physical Review is a distinguished physics journal that has been published continuously since 1893. We will assume that a volume is published twice a year. After about 1935 there was a sharp increase in the number of articles that were published in each volume making it thicker and thicker such that, when it was stacked on the library shelf every six months, the front cover of the journal could be said to be moving along with an ever increasing velocity. A physicist at the time pointed out that if this continued then the front cover of the journal would eventually exceed the speed of light (but then according to relativity theory there would be no information transmitted).

We assume a simple model:

- that the number of articles per volume increase exponentially, doubling every six months (the articles are of similar length)
- at the beginning of 1935 the volume was 1 cm thick
- that the velocity of the front cover is the thickness of that volume divided by the number of seconds in six months.

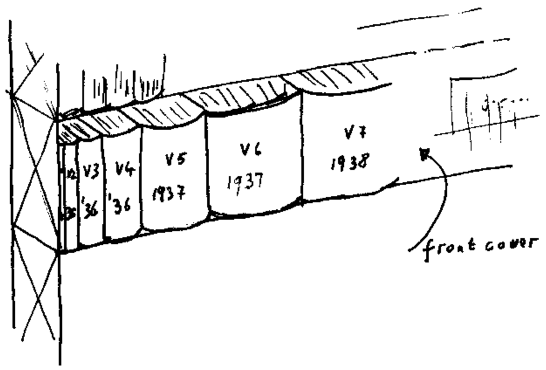


Figure 2. Volumes of the Physical Review doubling in thickness every six months.

You must show your working in the following questions.

a) By what factor does the thickness of the volume increase each year?

b) What would be the thickness of the volume put on the shelf at the beginning of 1940?

c) Write down your answer to (b) to one significant figure and in standard form.

d) Using your answer to part (c), write down the thickness of each volume for the next three years.

e) Determine the year when the front cover of the volume stacked will exceed the velocity of light. You may find it helpful to write your answer to part (d) including a term of the form 4^n.

Hint: use logs to base 10

$$\log_{10} x^n = n \log_{10} x$$

(10 marks)

Question 5

There are several factors which determine the maximum height of a mountain. Everest at only 8 km is not very high in terms of the maximum height that can be attained given the strength of the rock. All mountains on Earth suffer from erosion which reduces their height significantly. The maximum height is limited by the rock flowing under the enormous weight above it, which is related to the Young's Modulus value for the rock, *E*. We can suggest that an equation for the maximum height of a mountain would depend upon the density of the rock, ρ, Young's Modulus, *E*, and the strength of Earth's gravity, *g*. An insight into the solution of a problem can often be made by looking at the dimensions of the relevant physical quantities.

a) *E* is a measure of how much the rock deforms when a load is applied to it. *E* has units of N m^{-2}. Write down the units of *E*, ρ and *g* in terms of meters, kilograms and seconds (m, kg, s).

b) If the height of the mountain is given by the formula $h = \text{constant} \times E \times \rho^{\alpha} \times g^{\beta}$, by comparing the units on the left and right hand sides of the equation (the constant has no units), determine the values of α and β and write down the equation for *h*.

c) If the value of *E* for rock is 10^{10} Pa, the density of rock is $3 \times 10^{3}\ \text{kg m}^{-3}$ and the value of the constant is 1, estimate to one significant figure the height of a mountain that will be given by the formula. (Such a mountain is to be found on Mars).

(9 marks)

Question 6

When liquid nitrogen at a temperature of 77 kelvin or -196 ^{o}C is poured into a beaker, it is observed to boil continuously as heat enters it from the surroundings. When stored in a full 25 litre Dewar flask (an insulated steel container similar to a thermos flask), it takes 100 days for all of the liquid nitrogen to boil away. The rate at which heat enters (i.e. power entering) the Dewar flask is very low and we can estimate the value using the results of the following experiment.

Figure 3. Liquid nitrogen Dewar

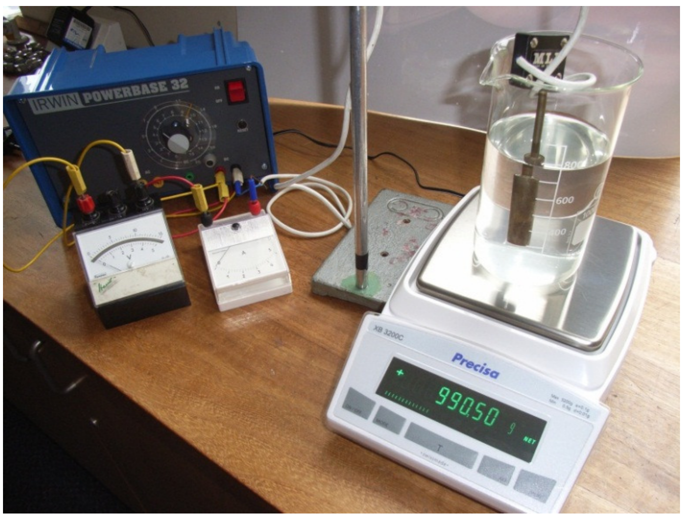


Figure 4. Electrical heater suspended in liquid nitrogen

A beaker of liquid nitrogen is placed on an electronic balance and readings of the mass are taken every twenty seconds. A small electrical heater is suspended in the liquid, and the experiment is carried out twice, once with the heater turned off and then repeated with the heater connected to the electrical supply. A graph is plotted of the two sets of results and the lines of best fit are obtained, along with the equations. The graph is shown below.

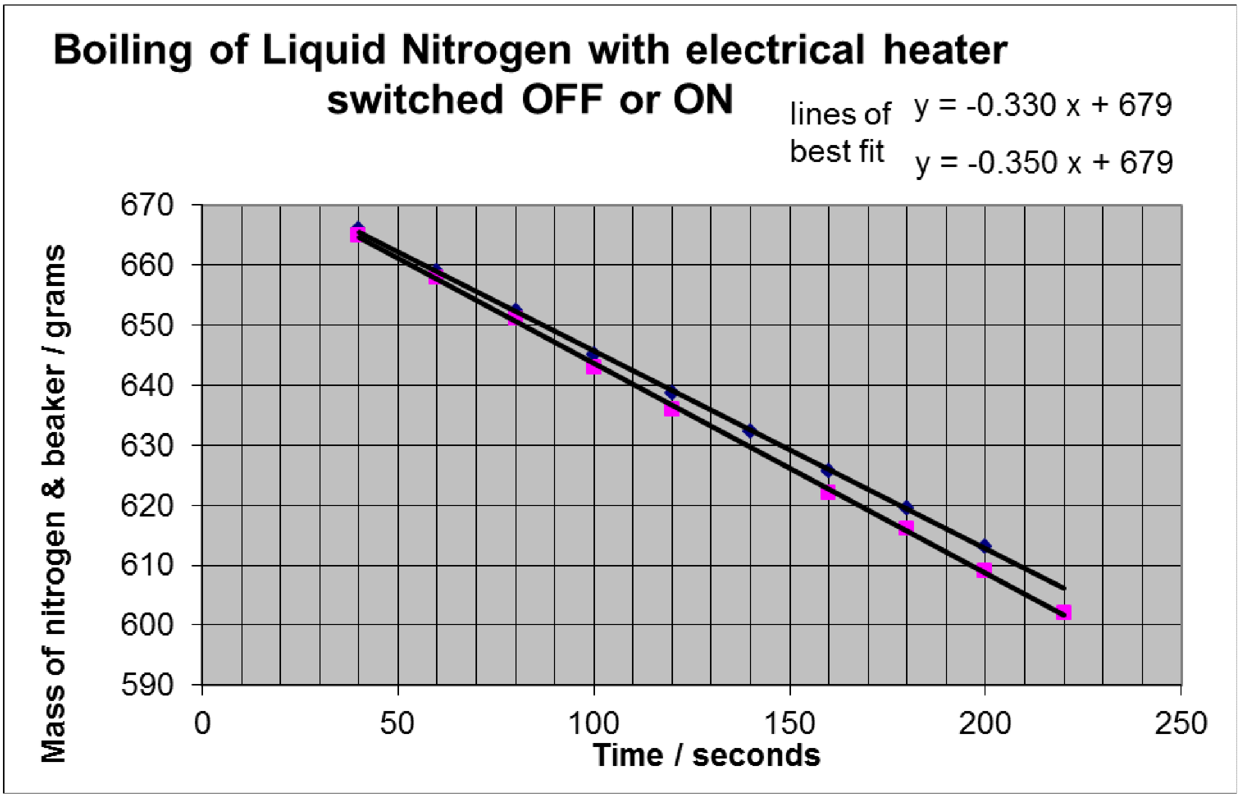
a) Calculate the rate of loss of liquid nitrogen in grams per second, for each of the two cases, using the data from the graph. The equations for the lines of best fit are given.

b) The heater supply is V=3.9 volts, I=1.2 amps. Calculate the number of joules per second supplied by the heater.

c) Calculate the energy from the heater required to boil away one gram of liquid nitrogen.

d) Calculate the heat power from the room entering the beaker of nitrogen.

e) Calculate the average power that must enter the full 25 litre Dewar to boil away the nitrogen in 100 days. Density of liquid nitrogen is 810 kg m^{-3} (1 m^3 = 1000 litres).



(12 marks)

[End of Questions]