BRITISH PHYSICS OLYMPIAD

British Physics Olympiad 2011

Paper 3

Monday 28th February 2011

Time allowed 3hrs plus 15 minutes reading time. There are three questions. Graph paper and a scaled rule are needed for this examination. Attempt all questions. A standard formula sheet may be used.

Speed of light in free space	c	3.00×10^{8} m s^{-1}
Elementary charge	e	1.60×10^{-19} C
Acceleration of free fall at Earth's surface	g	9.81 m s^{-2}
Permeability of free space	μ_o	$4\pi \times 10^{-7}$ Hm^{-1}
Refractive index of water	n_w	1.33
Mass of a neutron	m_n	1.67×10^{-27} kg
Mass of a proton	m_p	1.67×10^{-27} kg
Boltzmann constant	k	1.38×10^{-23} JK^{-1}
Planck constant	h	6.62×10^{-34} Js

Please attach the Paper 3 cover sheet to the answer sheets and return to the following address by 8th March 2011:

A.G.Bagnall,
2St Peter's Barn
West Knighton
Dorchester
Dorset
DT2 8PF

Note:
Please email bagnall@stpeters5.demon.co.uk giving details of date time etc of despatch.
Please use **normal 1st class** post.
It would be wise to retain a photocopy of the script.

Q1

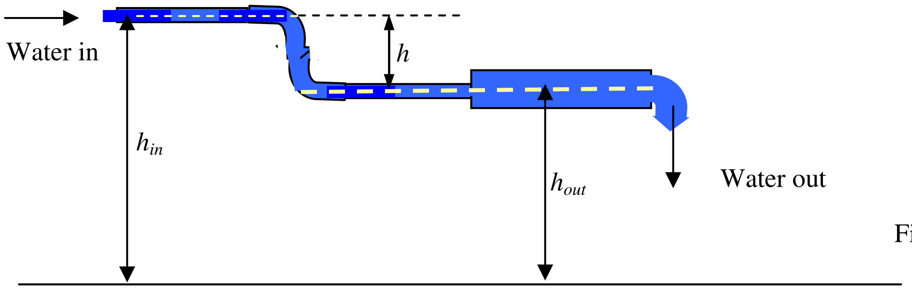


Figure 1.a

(a) Figure 1.a shows a schematic drawing of part of a water system. The cross sectional area of the in pipe is a_i and the cross sectional area of the out pipe is a_o. What characteristics distinguish this system from similar pipes that contain a gas rather than water? Bernoulli's equation gives:

$$p + \frac{1}{2}\rho v^2 + \rho g h = \text{constant}$$

p, pressure ρ, density

Write down an equation that relates p_{in}, v_{in}, h_{in} to $p_{out}, v_{out}, h_{out}$, What does Bernoulli's equation assume?

(b)

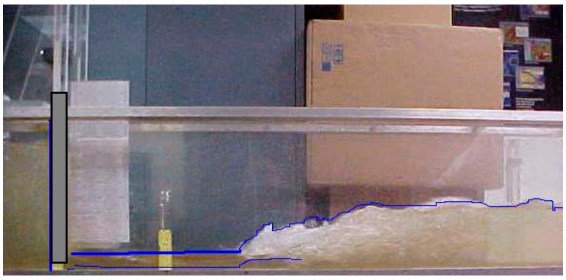


Figure 1.b.1

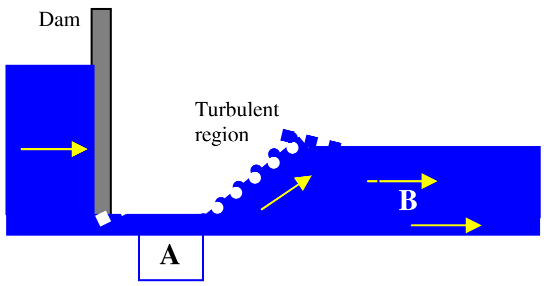


Figure 1.b.2

Figure 1.b.1 and Figure 1.b.2 show the action of water flowing under an obstacle (dam).

Figure 1.b.1 shows a photograph of a hydraulic jump with a turbulent region where the water rises and Figure 1.b.2 is a diagram that shows the principal features of a hydraulic jump. Assuming that the width of the channel is constant, write down equations that predict the flow speed immediately before (region A) and after the turbulent region (region B).

(c) Describe in detail the energy changes that occur to the water in the channel.

Part (d) follows on page 3

(d) Read the following passage and answer the questions at the end.

D-D fuel cycle

N.B. D is the same as ^2H

Though more difficult to facilitate than the deuterium-tritium reaction, fusion can also be achieved through the reaction of deuterium with itself. This reaction has two branches that occur with nearly equal probability:

$$^2H + ^2H \rightarrow ^3H + p + 4.0\text{MeV} \quad \text{(p is a proton)}$$

$$^2H + ^2H \rightarrow ^3He + n + 3.3\text{MeV} \quad \text{(n is a neutron)}$$

The optimum temperature for this reaction is 15 keV, only slightly higher than the optimum for the D-T reaction. The first branch does not produce neutrons, but it does produce tritium (^3H), so that a D-D reactor will not be completely tritium free, even though it does not require an input of tritium (^3H) or lithium.

$$^3H + ^2H \rightarrow ^4He + n + 18.3\text{MeV}$$

Most of the tritium produced will be burned before leaving the reactor, which reduces the tritium handling required, but also means that more neutrons are produced and that some of these are very energetic. The neutron from the second branch has an energy of only 2.45 MeV (0.393 pJ), whereas the neutron from the D-T reaction has an energy of 14.1 MeV (2.26 pJ), resulting in a wider range of isotope production and material damage.

The primary advantage of the D-D fuel cycle is that tritium breeding is not required. Other advantages are independence from limitations of lithium resources and a somewhat softer neutron spectrum. The price to pay compared to D-T is that the energy confinement (at a given pressure) must be 30 times better and the power produced (at a given pressure and volume) is 68 times less.

Questions

(i) Explain what is meant by "*The optimum temperature for this reaction is 15* keV" .

(ii) What is this temperature in Kelvin?

(iii) Paraffin wax is good at stopping neutrons. Why?

(iv) Explain why the neutron from the D-T reaction has an energy of 14.1 MeV.

(v) Why is tritium difficult to handle?

(vi) What does "a somewhat softer neutron spectra" mean?

One way of bringing the deuterium to the point of criticality is to compress a small spherical capsule of it using multiple laser beams. Derive an expression for the momentum of light quanta of frequency *f*. Find the pressure produced on a 1mm diameter sphere using a laser of power 1MW with multiple beams that are spread around the sphere giving a uniform symmetrical pressure, see Figure 1.d.a.

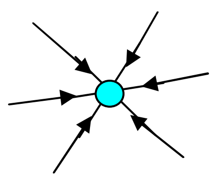
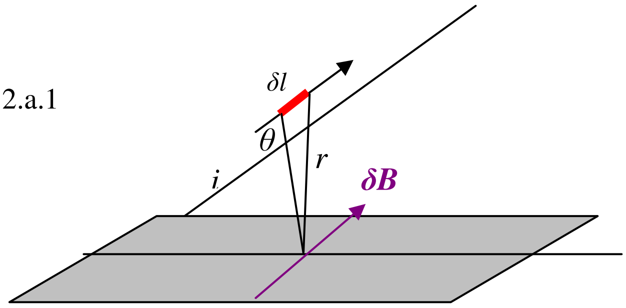


Figure1.d.a

Q2

(a) Figure 2.a.1



The law of Biot-Savart states that if a current i is flowing in a wire at an angle θ to a plane then the magnetic flux density δB ,as shown, is given by:

$$\delta B = \frac{\mu_0 i \delta l \sin\theta}{4\pi r^2}$$ See Figure 2.a.1.

Hence show that a current i flowing through a single straight very long wire will cause a field of $B = \frac{\mu_0 i}{2\pi r}$ as shown in Figure 2.a.2.

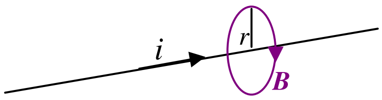
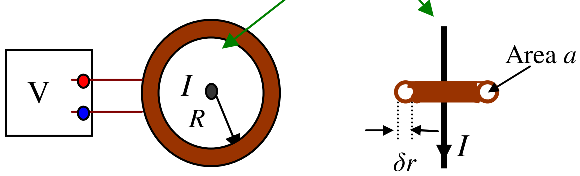


Figure 2.a.2

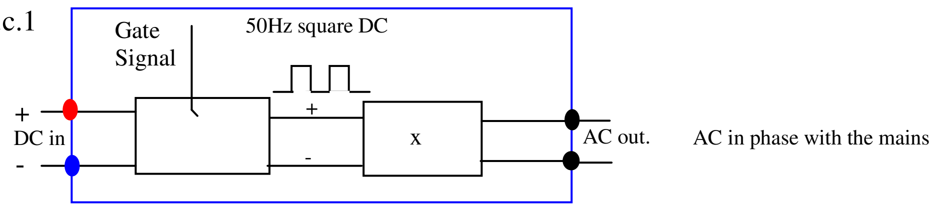
(b) Figure 2.b.1



A copper wire carrying a current of I is shown in Figure 2.b.1. A toroidal coil, radius R, wound with copper wire carries a current I. The toroid has N turns of wire and the cross sectional area of the ring is a, diameter δr. If the current in the vertical wire changes at a rate of $\frac{dI}{dt}$, what will the voltmeter read? (Assume $\delta r << R$).

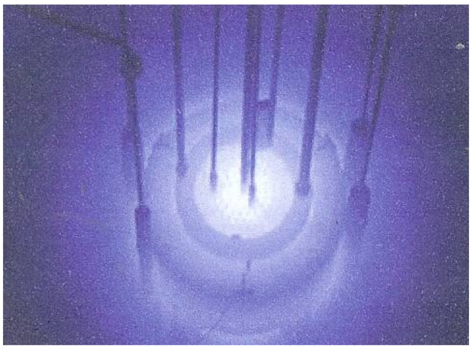
(c) A device called an inverter can be use to change DC into AC. A "tied" inverter connects a DC supply to the 240V 50Hz mains so that the p.d. produced by the inverter is sinusoidal and in phase with the mains. An example of the use of an inverter is to enable a photovoltaic panel to supply power to the grid. A block diagram of the type of circuit that could be used in an inverter is illustrated in Figure 2.c.1.

Figure. 2.c.1

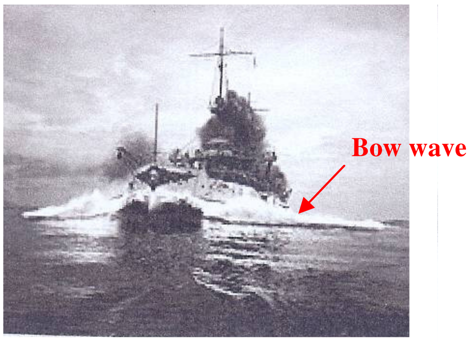


The steady DC is interrupted by the gate signal that produces an interrupted DC signal in phase with the mains. Suggest components that should be inserted in the box (x) to make the output sinusoidal and justify this choice by numerical calculations if appropriate.

Q3



Photograph 3.1



Photograph.3.2

(a) An electron is accelerated in an evacuated chamber. Sketch lines that illustrate how the magnetic field produced by the electron will vary with time.

(b) It is possible that charged particles can go through a medium such as water or glass faster than the speed of light in that medium. Consider a boat travelling along on the surface of the water, the disturbance (the bow wave Photograph 3.2) will spread in a way similar to the wave produced by series of circles caused by small stones dropped in the water in succession, 1 to 6, equally spaced in time and distance. This is shown in Figure 3.b.1.

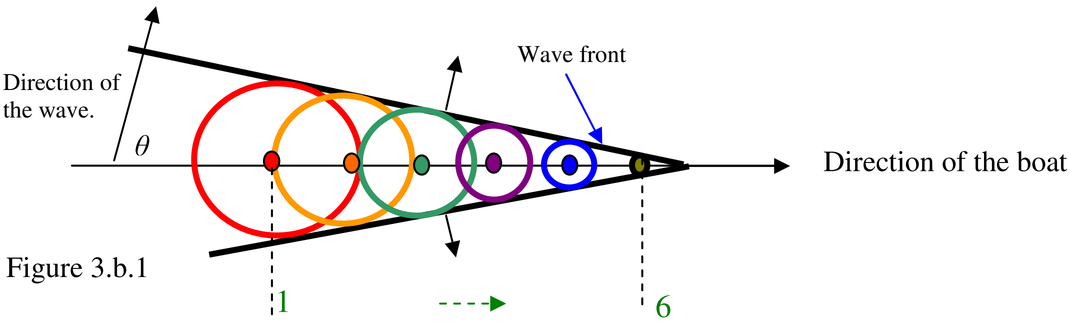


Figure 3.b.1

Find the value of the angle, θ, that the bow waves make with direction of the boat given that the speed of the boat is 5 ms^{-1} and the speed of the waves is 2ms^{-1}. The bow wave is illustrated in Photograph 3.2.

(c) Photograph 3.1 shows Cherenkov radiation, in the form of blue light, being produced by radioactive particles moving through water faster than the speed of light through water. Find a formula that relates the speed of the particles, v_p, to the refractive index of water, β $\left(\beta = \frac{v_p}{c}\right)$ and θ. Theta (θ) is the angle that the emerging light makes with the incoming particle. Why is blue light observed?

(d) Use a very simple model to find how the Earth's temperature should vary with latitude. Comment how your model compares with what is observed.

END OF PAPER.

Please make sure you have numbered your pages. Fill in the Paper 3 cover sheet and make sure it is firmly attached to your script.