AS CHALLENGE PAPER 2015

Name	
School	

Friday 13th March

Total Mark/50

Time Allowed: ***One hour***

Attempt as many questions as you can.

Write your answers on this question paper.

Marks allocated for each question are shown in brackets on the right.

You may use any calculator.

You may use any public examination formula booklet.

Allow no more than ***6 or 7 minutes*** *for* ***section A.***

Scribbled or unclear working will not gain marks.

This paper is about problem solving. It is designed to be a challenge for the top AS physicists in the country. If you find the questions hard, they are. Do not be put off. The only way to overcome them is to struggle through and learn from them.

Good Luck.

Useful constants and equations

$$c = 3.00 \times 10^{8}\ \text{m s}^{-1}$$
$$h = 6.63 \times 10^{-34}\ \text{J s}$$
$$e = 1.60 \times 10^{-19}\ \text{C}$$
$$m_{\text{neutron}} = 1.67 \times 10^{-27}\ \text{kg}$$
$$m_{\text{proton}} = 1.67 \times 10^{-27}\ \text{kg}$$
$$g = 9.81\ \text{m s}^{-2}$$

$\text{surface area of a sphere} = 4\pi r^2$ $\text{volume of a sphere} = \frac{4}{3}\pi r^3$

$s = ut + \frac{1}{2}at^2$ $v^2 = u^2 + 2as$ $v = u + at$

$\text{power} = \text{force} \times \text{velocity}$ $P = E/t$ $v = f\lambda$ $n = \frac{\sin\theta_{air}}{\sin\theta_{water}}$

$V = IR$ $R = R_1 + R_2$ $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$

Section A: Multiple Choice

Circle the correct answer to each question. Write your answers in the table at the end of the multiple choice questions on page 2.

Each question is worth 1 mark. There is only one correct answer to each question.

1. The Sun has an energy output of 3.8×10^{26} W. It has a radius of 7.0×10^{5} km. An estimate of the average power produced inside the Sun per m^3 is:

   A. 6.2×10^{7} W B. 3.8×10^{3} W C. 1.1 W D. 0.26 W

2. The Earth has a mass of 6.0×10^{24} kg and an orbital velocity of 30 km s^{-1} about the Sun. What is its kinetic energy?

   A. 2.7×10^{27} J B. 9.0×10^{28} J C. 2.7×10^{33} J D. 5.4×10^{33} J

3. The second is now defined as the duration of 9 192 631 770 periods of the radiation corresponding to the transition between two energy levels of the of the cesium 133 atom. What is the wavelength of the radiation emitted?

A. 3.3 cm B. 3.3 mm C. 31 m D. 33 cm

4. A neutron has kinetic energy of 1.0×10^{-7} eV. If moving vertically, how high could it rise in the earth's gravitational field? (1 eV is the energy equivalent to an electron charge, e, moving through 1 volt)

A. 6.1×10^{16} m B. 9.8×10^{13} m C. 4.4 m D. 0.98 m

5. A particle slides from rest and without friction down a set of slopes of different gradients, as shown in figure 1. For each slope the particle reaches the bottom after:

A. Taking the same time

B. Undergoing the same acceleration

C. Reaching the same speed

D. Undergoing the same change of displacement

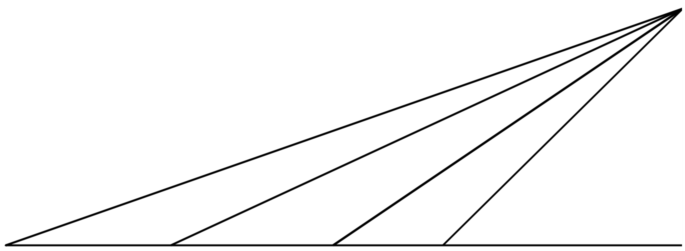

Figure 1. Set of smooth slopes.

Answers

Qu 1	Qu 2	Qu 3	Qu 4	Qu 5

Section B: Written Answers

Question 6.

In a hydroelectric power station, water falls down a pipe from a height to generate electricity. A mass of 2.0 kg of water is dropped from a height of 20 m. Work is done by gravity in accelerating the water. Neglect any frictional drag in a pipe.

a) What is the average power conversion during the fall?

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b) What is the instantaneous rate of energy conversion at the moment the water has fallen 20 m?

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____ [2]

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Question 7.

A circuit with three resistors in the form of a “T” arrangement is shown in figure 2 below. The resistor R_2 is not accessible and has to be determined by measurements between points A & B and then C & D. (the voltmeter is an ideal voltmeter with infinite resistance).

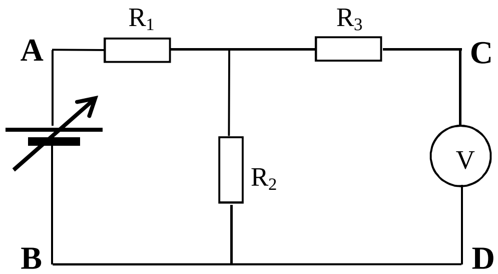


Figure 2. Circuit with T resistor arrangement and with a variable supply and voltmeter.

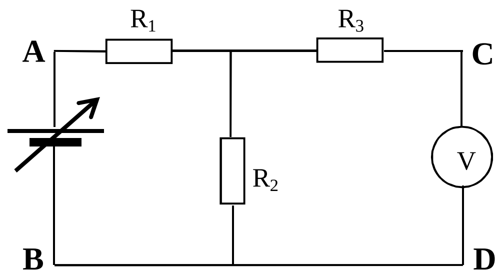
Measurement 1: 8.0 V is applied to AB and 5.0 V is measured between C and D. The current from the supply is 0.50 A.

The supply and the voltmeter are now interchanged for measurement 2.

Measurement 2: 10 V is applied to CD and 4.0 V is measured between A and B.

a) For each of the measurements, sketch the circuit (the first is done for you), and mark on the all information given, including the voltage values given and the paths of the current flow.

<u>Measurement 1</u>: **<u>Measurement 2</u>:**



[4]

b) Write down either one or two simple equations for each circuit, involving the current, voltages and the relevant resistances.

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c) Solve these equations to determine the values of R_1, R_2 and R_3.

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____ [3]

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Question 8.

A diver in a deep sea submarine views the sea bed through a glass porthole. The radius of the porthole is 0.1 m and is mounted in the floor of his vessel, as shown in figure 3. The thickness of the glass can be ignored for the calculation.

Refractive index of water is 1.33

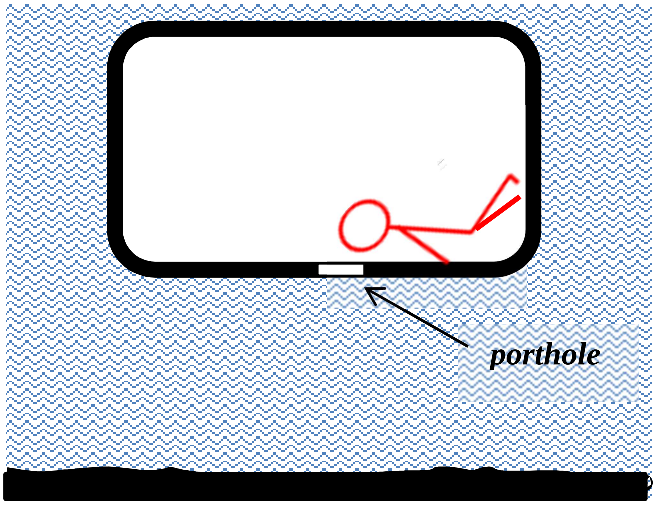

Figure 3. Deep sea observation submarine with circular glass porthole in the floor to view the sea bed.

a) With the aid of a clear diagram, explain why he can only view a small area of the seabed through the porthole, however close the diver puts his eye to the porthole.

____ [2]

b) If the floor of the vessel is 4.0 m above the seabed, determine the maximum area of the seabed that he can view.

____ [4]

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Question 9.

a) State what is meant by equilibrium in the context of forces.

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b) A student stands in the middle of a balanced plank which sits on rollers on top of a column. There is zero friction between the plank and the top of the column due to the excellent quality of the rollers. If the student walks (glides) to the right, smoothly and without bouncing state and explain, using Newton's Laws, what happens to the plank, and the balancing of the system on top of the column.

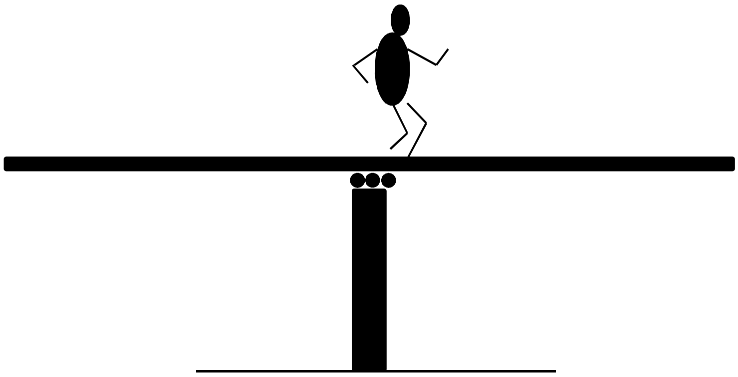

Figure 4. Student walking along a balanced plank, which is supported on frictionless rollers.

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____ [2]

c) A small ball is placed in the bottom of a bowl in figure 5a, and on the top of an inverted bowl in figure 5b. State what is meant by stable and unstable equilibrium using these examples.

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____ [2]

Figure 5. Ball (a) lying in, and (b) on top of a curved surface.

d) A solid rectangular block of height h and width w is placed on a plane inclined at an angle θ, as in figure 6. Friction prevents the block from sliding down the slope. What is the maximum angle of the slope, θ_{max} such that the block will remain upright?

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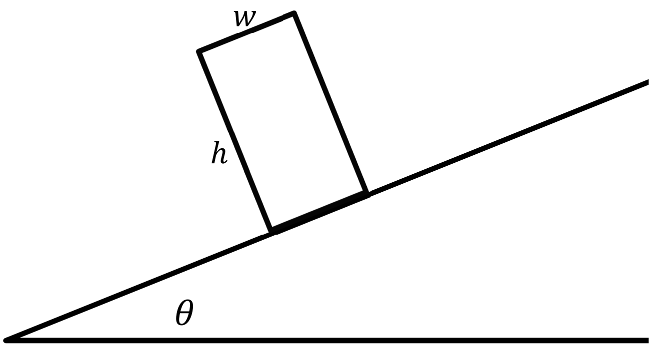

Figure 6. Block of height, *h* and width, *w*.

e) A massive solid cube of side $\ell = r\frac{\pi}{2}$ and of uniform density is placed on highest point of a cylinder of radius r, as shown in figure 7. If the cylinder is rough so that no sliding occurs, calculate the full range of the angle through which the block can swing (or wobble) without tipping off. (you can assume that this range of equilibrium positions is stable).

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____ [4]

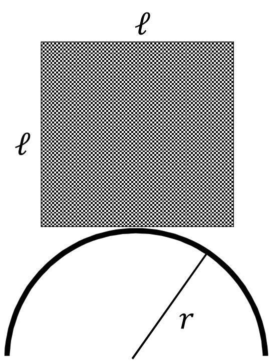

Figure 7. Square block of side $\ell = r\frac{\pi}{2}$ on a cylindrical surface of radius, *r*.

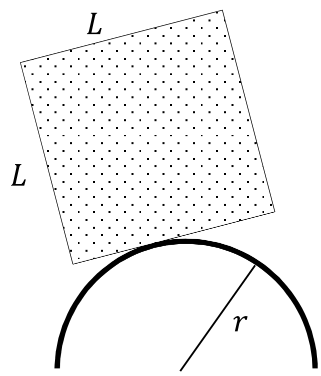

Figure 8. Large block which just balances on the cylinder without tipping off.

f) If the block was made very large as in figure 8, it would still be stable for small displacements. What would be the largest value of the side of length L for which the block would be stable? (You may draw clear construction lines on the diagram, or draw your own).
(You may use the result that as $\theta \to 0$ then $\frac{\theta}{\tan\theta} \to 1$, which is its largest value.)

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____ [4]

Question 10.

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The Sun emits light (and other parts of the electromagnetic spectrum). The light can be described in terms of particles called photons. The energy of a single photon E_{ph} is given by $E_{ph} = hf$, where h is Planck's constant and f is the frequency of the light. The photon also has a momentum, somewhat like the particles in a gas, and will produce a force F on a reflecting surface, given by $F = 2E_{ph}/c$ (the factor "2" is because the photons arrive and get reflected back).

A spacecraft can be driven by a 'solar sail', of unknown dimensions, which consists of a large sheet of reflective material kept facing the Sun. When a photon from the Sun hits the sail it is reflected off and, as a result, the sail experiences a force. **Consider one square metre of area**. If n photons (per square metre) are reflected each second, then the average force will be given by

$F_{av} = \frac{2nE_{ph}}{c}$ per square metre.

As photons spread out radially from the Sun, the intensity of photons (the number crossing each square metre of a sphere surrounding the Sun every second) follows an inverse square law, *i.e.* n is proportional to $\frac{1}{r^2}$, where r is the distance measured from the centre of the Sun.

A solar sail fixed to a spacecraft, with the full area of the sail facing the Sun, causes an acceleration of 1.2 $\mathrm{mm\,s^{-2}}$ when the spacecraft is far from the Sun, crossing the orbit of Jupiter. With this low mass satellite you can ignore any other effects.

Assume that the photons correspond to a wavelength of 549×10^{-9} m. The total number of photons reaching the Earth from the Sun, $n_{\mathrm{E}} = 3.6 \times 10^{21}\ \mathrm{m^{-2}\ s^{-1}}$.

Data: $\lambda_{light} = 549 \times 10^{-9}$ m
Number of photons per square metre reaching
the Earth each second = $3.6 \times 10^{21}\ \mathrm{m^{-2}\ s^{-1}}$.
Distance Sun - Earth = 150×10^{6} km
Distance Sun - Jupiter = 780×10^{6} km
Mass of spacecraft = 150 kg

a) Calculate the area of the sail, A.

[Here is a set of quantities that might prove useful in obtaining the result:
E_{ph}, n_{J} (at Jupiter), ma, total force on the sail].

<u>Work out any quantities that you can</u> and make it clear what each result is. There is no particular order.

[7]

b) If the mass of the spacecraft was about five times greater, the acceleration drops to almost zero. This is true at Jupiter's orbital distance from the Sun or the Earth's orbital distance, or in fact at any distance from the Sun. Why is this?

[2]

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END OF PAPER