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NZEST SCHOLARSHIP EXAMINATION 1996

PHYSICS

Friday 8 November 1996, 2pm

To issue: Standard NZEST Answer Book

Time allowed: THREE hours

INSTRUCTIONS TO CANDIDATES

1. The paper consists of 10 questions. Attempt all questions.

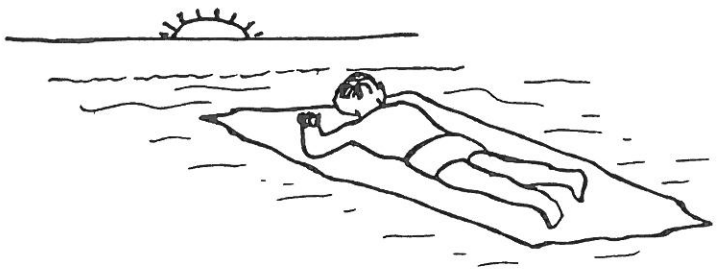
2. The marks for each question are not equal and vary from 13 to 21. The total marks aggregate to 160. Candidates are advised to invest their time in proportion to the marks indicated.

DATA WHICH MAY BE REQUIRED

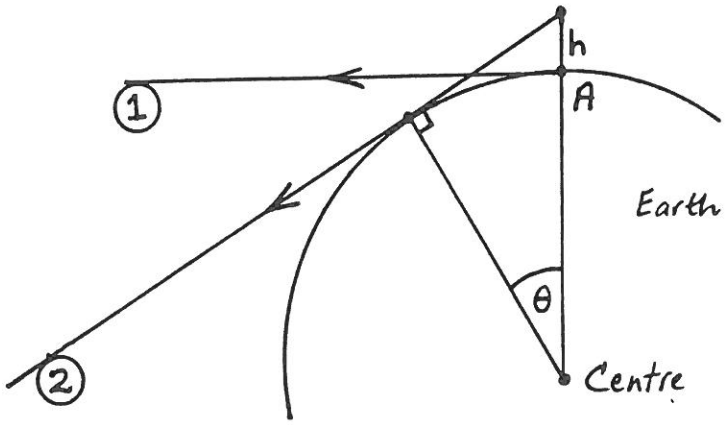
Acceleration of gravity	g	=	$9.80\ \text{ms}^{-2}$
Permittivity of free space	ε_0	=	$8.85 \times 10^{-12}\ \text{F m}^{-1}$
Permeability of free space	μ_0	=	$4\pi \times 10^{-7}\ \text{H m}^{-1}$
Electronic charge	e	=	$1.60 \times 10^{-19}\ \text{C}$
Planck's constant	h	=	$6.63 \times 10^{-34}\ \text{J s}$
Speed of light	c	=	$3.00 \times 10^{8}\ \text{m s}^{-1}$
Speed of sound		=	$330\ \text{m s}^{-1}$

Question 1 *[17 marks]*

(a) Surf-seeker Sam watches the sun set whilst lying on a beach near the equator. At the moment the sun disappears he starts a stop watch. This is sunset 1.



He then stands up and, with his eyes now at height h above his previous viewpoint, observes that the sun has not quite set but soon does so, at 11.1s on the watch. This is sunset 2.



A schematic diagram of the situation is shown above. This is a cut away view of the Earth toward the South Pole from space; the Earth has been sliced through the equatorial plane and the southern hemisphere removed. The sun is setting in the West and Sam is at A.

The geometry is simple if we assume, as we will, that the Earth's equatorial plane is not tilted to, but is the same as, the Earth's orbital plane around the sun.

(i) Argue that θ must be 0.0463° [2 marks]

(ii) Use the diagram to deduce that $\cos\theta = \dfrac{R}{(R+h)}$ where R is the Earth's radius. [1 marks]

(iii) Given that h is 2.07 m show that R is 6.34 10^6 m. [4 marks]

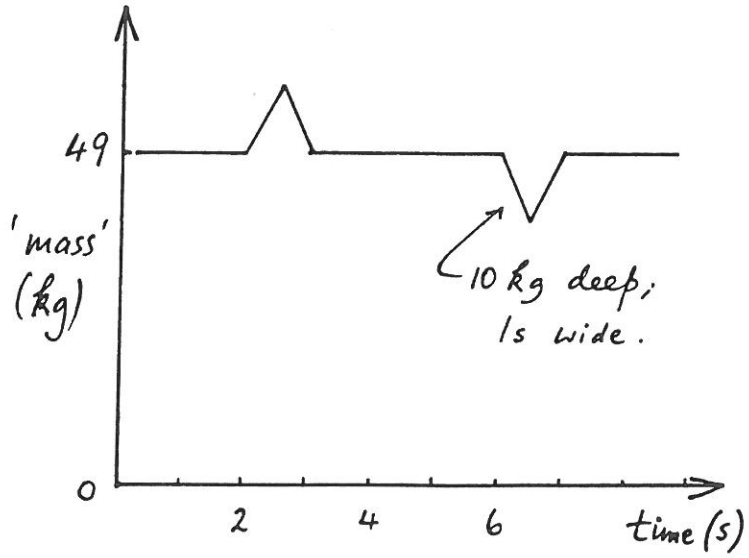
(b) (i) What would be the length of a day if the Earth turned around its North-South axis so rapidly that a person on the equator had no weight? [5 marks]

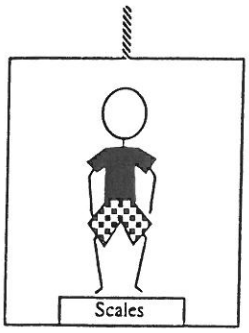
(ii) Would this person then have weight at the South pole? Comment. [2 marks]

(iii) Would the Earth now have an atmosphere? Comment. [3 marks]

Question 2 *[14 marks]*

(a) A person, mass 49 kg, stands on bathroom scales in a lift. The scales are calibrated in kg. After pressing the button the lift moves from one floor to another. The reading on the scales was observed to change with time as shown below.





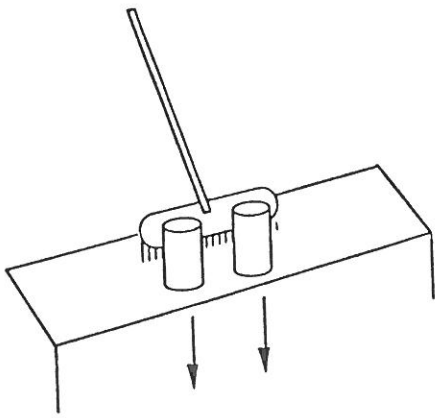
(i) In which direction, up or down, did the lift move? Comment. [2 marks]

(ii) Calculate the maximum acceleration of the lift. [2 marks]

(iii) Sketch the shape of the acceleration /time graph for the motion. [2 marks]

(iv) Sketch the shape of the velocity /time graph for the motion and hence estimate the distance between stops. [4 marks]

(b) In the student cafe two students argue as to which of two Coke® cans - one full, one empty - would reach the ground first if they fell freely from a height after simultaneous release. To settle the argument one student goes to the top of the building and pushes the cans off while the other watches below.



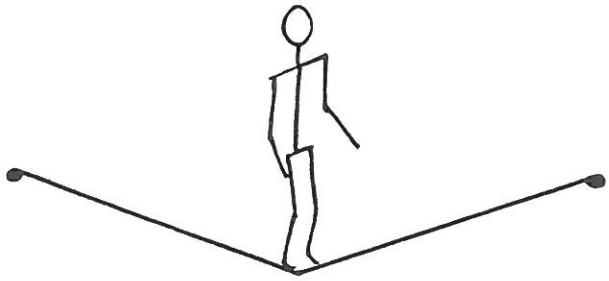
Do the cans hit together, or not? Carefully explain. [4 marks]

Question 3 *[21 marks]*

When a gymnast of mass 70.0 kg stands on the center of the trampoline the mat is displaced downwards by 0.330 m. When two such gymnasts stand together on the mat the displacement doubles.

(i) Show that k, the 'spring constant' for the mat, is 2080 N m^{-1}. [1 mark]

(ii) Standing still and without flexing, one gymnast, alone on the mat, executes small vertical oscillations. With the help of $T = 2\pi\sqrt{m/k}$, calculate the period of these oscillations if the gymnast's feet are at all times in contact with the mat. [1 mark]

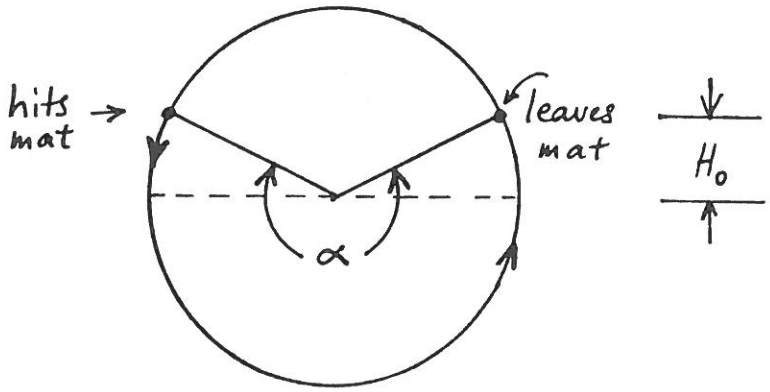


(iii) The gymnast then climbs a platform to a point above the trampoline and steps off onto the mat, 1.50 m below. Using an energy argument, or otherwise, and assuming the mat has negligible mass, show that the maximum downward displacement of the mat, initially flat, is 1.38 m.

Note: The solutions of the quadratic equation $ax^2 + bx + c = 0$ are

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}.$$ [4 marks]

(iv) The reference circle picture below schematically describes the SHM of the gymnast when in contact with the mat.
What is the value of H_o? Argue that the circle radius is 1.05 m. [3 marks]



(v) Determine the angle α. [2 marks]

Question 3 continued over the page.....

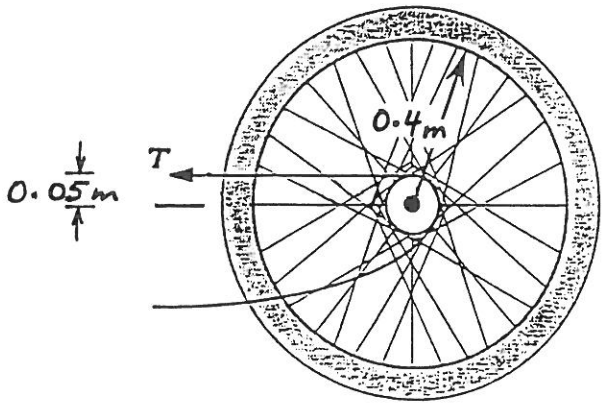
(vi) Hence determine the time for one complete 'oscillation' - that is, from the moment the gymnast leaves the platform to the moment she returns. [4 marks]

(vii) A friend on the platform hands the bouncing gymnast a heavy exercise ball the moment she reaches the top of a bounce. Briefly explain, without calculation, the change which will occur in:

(1) the maximum downward displacement of the mat [2 marks]
(2) the maximum height reached by the gymnast [2 marks]
(3) the period of vertical oscillation [2 marks]

Question 4 *[18 marks]*

(a) A motorcycle rear wheel, with light spokes, is driven by a chain connected to a sprocket of radius 0.0500 m on the axle, as shown. The wheel is free of the ground due to the motorcycle being placed on a stand. The chain tension is applied in the upper section while the lower section is 'loose'. The mass of the wheel is 10.0 kg and is effectively concentrated in the rim, at 0.400 m radius.



(i) Show that the moment of inertia of the wheel is 1.60 kg m^2 and explain why the inertia of the axle can be neglected. [3 marks]

(ii) When constant tension is applied to the chain, the wheel accelerates uniformly from rest to a speed of 20.0 rad/s in a time of 2.00 s. Given that the sprocket radius is 0.0500 m, calculate the magnitude of the tension in the chain. [3 marks]

(iii) Through how many radians did the wheel rotate in accelerating from rest as given in (ii)? [1 marks]

(iv) Calculate both the kinetic energy and angular momentum of the wheel when it is rotating at 20.0 radians per second. [2 marks]

(b) The motorcycle above is now taken off the stand and placed on the road. The total mass of the cycle plus rider is 200 kg and the front wheel of the cycle has identical dimensions to the rear wheel. The rider starts the cycle from rest and accelerates uniformly until the rotational speed of the rear (and the front) wheel is again 20.0 radians per second.

(i) Calculate the speed of the cycle along the road. You may assume that the outer radius of the tyre is 0.420 m and make use of the relation $v = r\omega$. [2 marks]

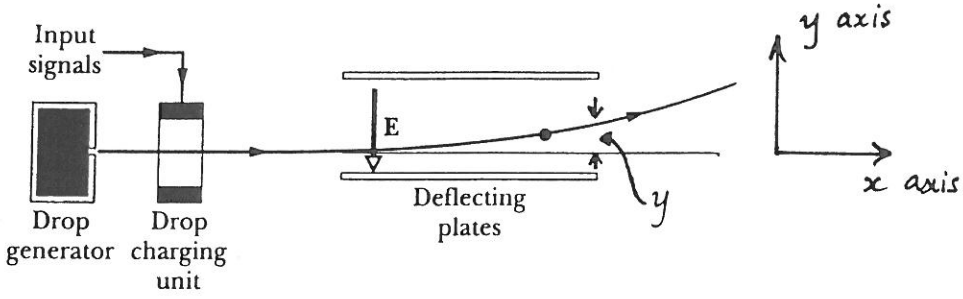
(ii) What is the total kinetic energy of the (cycle + rider)? [2 marks]

(iii) Assuming the same chain tension as in part (b)(ii) was used to accelerate the cycle, use a 'Work Done = Energy Gained' argument to determine the number of radians turned through by the wheel to reach the angular speed of 20 rad/s. Note: the equation $W = \tau\theta$ is useful here. [2 marks]

(iv) Hence determine the new angular acceleration and, from this, the time required to reach the 20 rad/s wheel-rotation speed, starting from rest. [3 marks]

Question 5 *[16 marks]*

(a) One type of computer printer - the ink jet printer - squirts a stream of tiny ink dots at the paper to form a letter. The figure below shows the drop generator (producing a stream of uncharged drops), the drop-charging unit, and the metal deflection plates.



Suppose an ink drop of mass m, charge q, enters the deflection plates of length L and electric field E with velocity v_x.

(i) Argue that the acceleration in the y direction has the constant value qE/m. [1 mark]

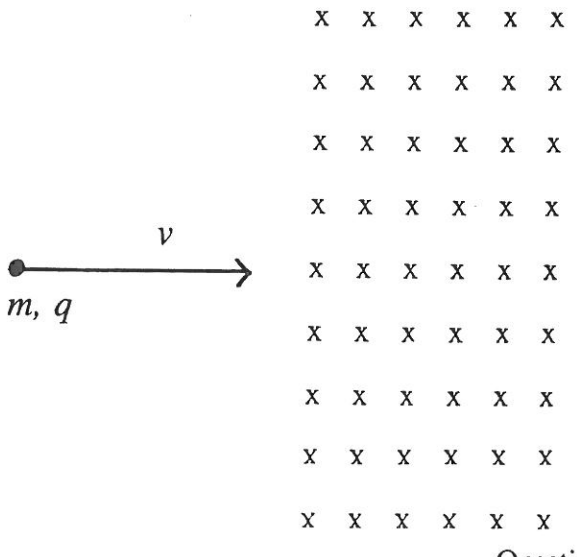
(ii) Write down an equation for the time taken for the drop to cross the deflection plates in the x-direction and hence show that the displacement of the drop in the y-direction when leaving the plates is

$$y = \frac{qEL^2}{2mv_x^2}.$$ [3 marks]

(iii) Evaluate y for a typical system for which the drop has mass $1\text{x}10^{-10}$ kg, charge $1.2\text{x}10^{-13}$ C and speed 18 m/s. Assume the plates are 0.016m long, and have a voltage of 14 kV across the 0.01 m gap. [3 marks]

(iv) How many electrons were added to the initially-neutral drop as it passed through the charger unit? [1 mark]

(b) Suppose the drops are shot at right angles into a uniform magnetic field, as shown (there is no electric field):



Question 5 continued over the page.....

Question 5 continued:

(i) Argue that the moving charge, under the influence of the magnetic field, will move in a circular path the radius of which is given by

$$r = \frac{mv}{qB}$$ [2 marks]

(ii) Show that the time for the particle to execute one half of the circle is:

$$t = \frac{\pi m}{qB}$$ [2 marks]

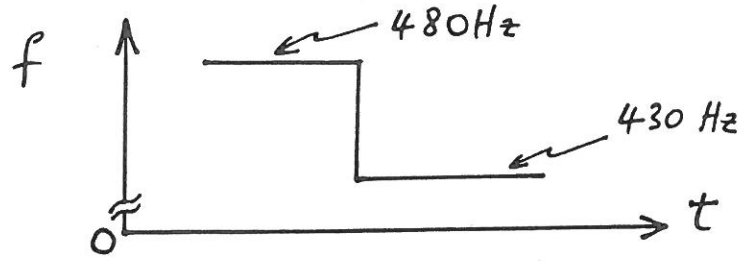
(iii) Show schematically, in a diagram, the location of the circle's centre and sketch the particle's path. [2 marks]

(iv) A steady magnetic field does not change the speed of a charged particle. Explain why this is so.

[2 marks]

Question 6 *[13 marks]*

(a) A speedboat passes with constant velocity close by a wharf. An observer on the wharf hears the frequency abruptly decrease from 480 Hz to 430 Hz as the boat speeds by, as shown.

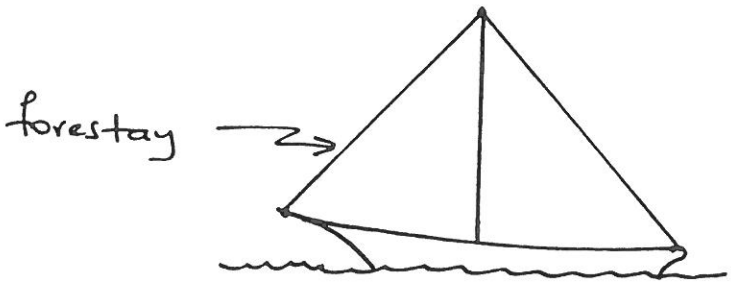


(i) Estimate (without maths) the frequency, f, heard by a person on the boat. [1 mark]

(ii) With the help of the Doppler relation $f' = c.f/(c \pm v)$ determine the speed of the boat. [2 marks]

(iii) Suppose the boat passed the wharf not close to, but at a significant distance from it, say 100 m or so. Show in a sketch how the above curve would then appear and briefly explain why. [2 marks]

(b) The tension in a yacht's rigging can be set correctly by striking the forestay cable and measuring its (low) frequency of vibration.



Suppose the forestay has a <u>total</u> mass of 0.3 kg and a length of 6.0 m.

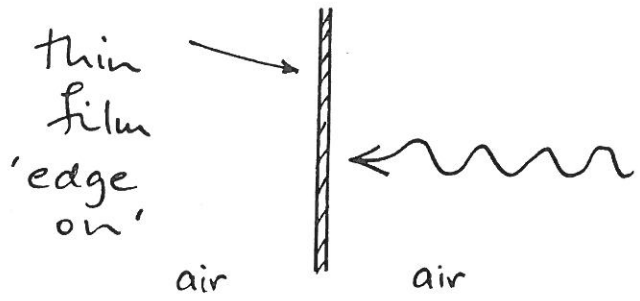
(i) With the aid of the equation for the wave velocity, $v = \sqrt{T/m}$, where T and m are the cable tension and the cable mass per metre length, respectively, determine the dominant frequency you would expect for a tension of 9000 N. [2 marks]

(ii) Other frequencies will be excited, but their persistence is less. Explain how these frequencies arise and why they quickly fade away. [2 marks]

Question 6 continued over the page.....

Question 8 *[16 marks]*

(a) Red light, of wavelength 720nm in air, is normally incident on a soap film, refractive index 1.33, as shown.



(i) For this red light, what are the values of c (the velocity) and λ in the film ? [2 marks]

(ii) When white light is shone on the film it is noticed that red light (λ = 720nm in air) and blue light (λ = 480nm in air) are not reflected. Remembering that light reflected from the front face of a film undergoes a phase shift equivalent to a path difference of $\lambda/2$, show that the film is probably about 540nm thick. Why 'probably'? [4 marks]

(iii) Argue that the film, in these circumstances, would have a green appearance in reflected white light. [1 mark]

(iv) Would the red and blue beams be transmitted by this film? Comment. [1 mark]

(b) Two loud speakers in an open field emit pure tones of 1000Hz and 1011Hz respectively. Observers A and B are at distances 20m and 70m from the loudspeakers, as shown; each hears 'beats'. However, when the sound is weakest for A, it is not weakest for B.

(i) What is the beat frequency? [1 mark]

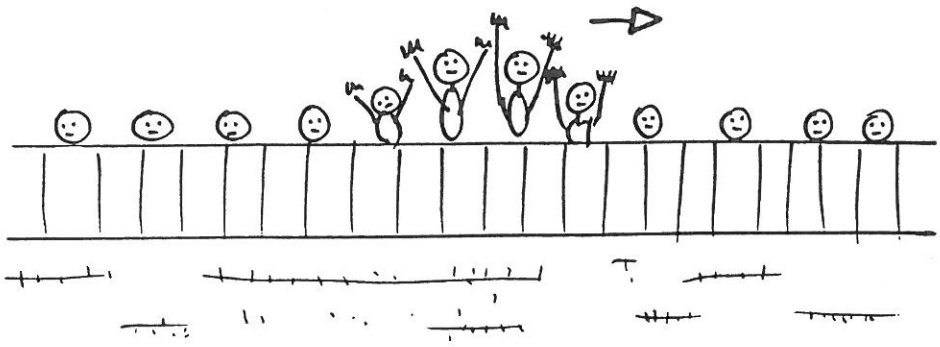
(ii) What is the 'distance' between beats? [1 mark]

(iii) If, at t = 0, the sound is weakest for A, show that it will next be weakest for B 0.061 s later. [2 marks]

Question 8 continued over the page.....

Question 8 continued:

(c) The 'Mexican wave' is a sporting ritual in which spectators on the sportsfield perimeter stand and raise there arms sequentially, creating a pulse of enthusiasm moving around the stadium.



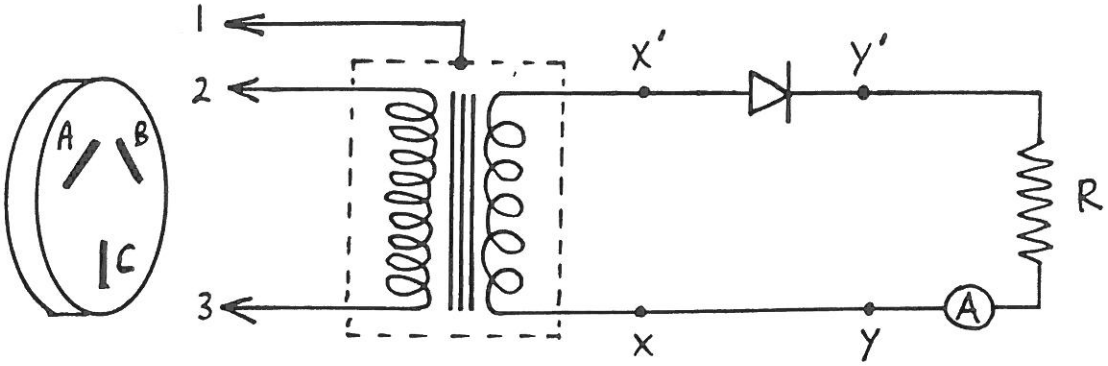
(i) Compare the mechanism of propagation to that of a wave on a wire. [2 marks]

(ii) Would the speed of propagation depend upon the mass of the individuals? [1 mark]

(iii) Consider two counter-propagating waves. Would the Principle of Superposition hold? [1 mark]

Question 9 *[13 marks]*

(a) A transformer, whose secondary winding is connected to a *diode plus DC ammeter plus resistor*, in series, has its primary winding connected to a 240V wall socket.



The primary/secondary turns on the transformer are as 1200 / 100. The resistance of R is 150 Ω. Wire #1 is attached to the metal case of the transformer.

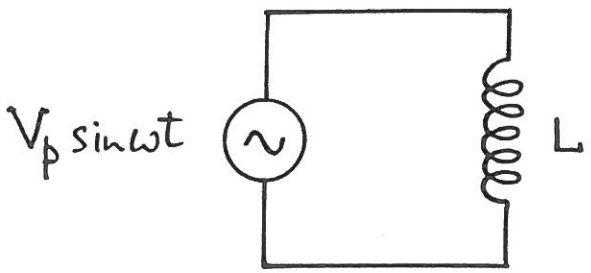
(i) To which wall socket connections, A, B and C, should/could wires #1,#2 and #3 be attached? [2 marks]

(ii) An oscilloscope is connected between points X X' in the circuit. Sketch one cycle of the voltage waveform that would be observed and attach scales to both the voltage and time axes. [3 marks]

(iii) Repeat part (ii) for the points Y Y', assuming an ideal diode. [2 marks]

(iv) Determine the power (in W) dissipated in the resistor. [2 marks]

(b) An AC generator, peak voltage V_p and angular frequency ω, is connected to an inductance L.

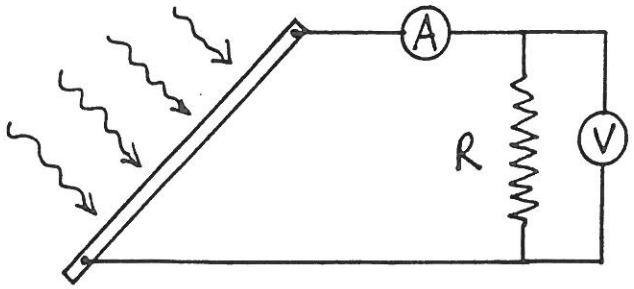


(i) Draw a phasor diagram for the voltage (V_p) applied across L and the current through it. [2 marks]

(ii) The inductor is removed and replaced by a capacitor. Draw a similar phasor diagram for this case. [2 marks]

Question 10 *[17 marks]*

(a) A solar cell (actually, a set of interconnected photo-voltaic cells), total area 1.00 m^2, is illuminated by direct sunlight of intensity 1.20 kW/m^2.



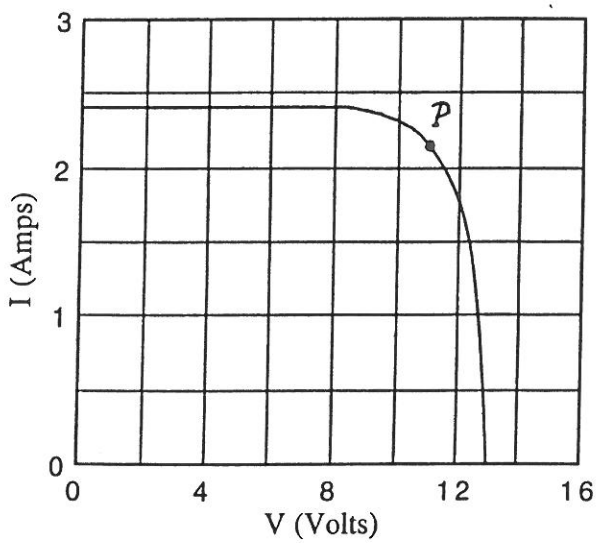
(i) In 4 hours of sunlight how many joules of radiant energy are received by the cell? [2 marks]

(ii) If all the photons are 'green', of wavelength 550nm, how many are received by the cell per second? [3 marks]

(iii) When the load resistor (R) is varied the current through it (I) and the voltage across it (V) behave as shown below. Write down the power developed in the resistor for the three cases:

(1) $V = 0.0$ V
(2) $I = 0.0$ A
(3) $V = 1.0$ V

[3 marks]



(iv) At point P the maximum power is developed in the load (because the load resistance then equals the internal resistance of the cell). Estimate from the graph the maximum power and the load resistance required for maximum power. [2 marks]

Question 10 continued over the page.....

Question 10 continued:

(v) The efficiency of a solar cell, usually small, is defined by:

$$\text{efficiency} = \frac{\text{electrical energy out}}{\text{solar energy in}}$$

Calculate the efficiency, in %, for the cell [1 mark]

(vi) What percentage of the generated energy is 'lost' within the cell - any cell - when the load and internal resistances are equal?

In what form is the energy lost? [2 marks]

(vii) So that the energy can be stored, R is now replaced by a car battery. The battery emf is 12V which indicates it is almost fully charged and has, therefore, negligible resistance. Estimate the current through the battery when first connected into the circuit. [2 marks]

(viii) When the sunlight weakens it is essential to stop the storage battery discharging (back) through the solar cell. One diode is enough. Show its location, and that of the car battery, in a sketch of the modified circuit.

Indicate the battery polarity. [2 marks]

END OF QUESTION PAPER