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NZEST SCHOLARSHIP EXAMINATION 1995

PHYSICS

Time allowed: THREE hours

Ten minutes extra are allowed for reading this paper

INSTRUCTIONS TO CANDIDATES

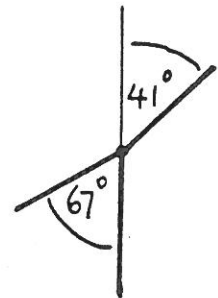
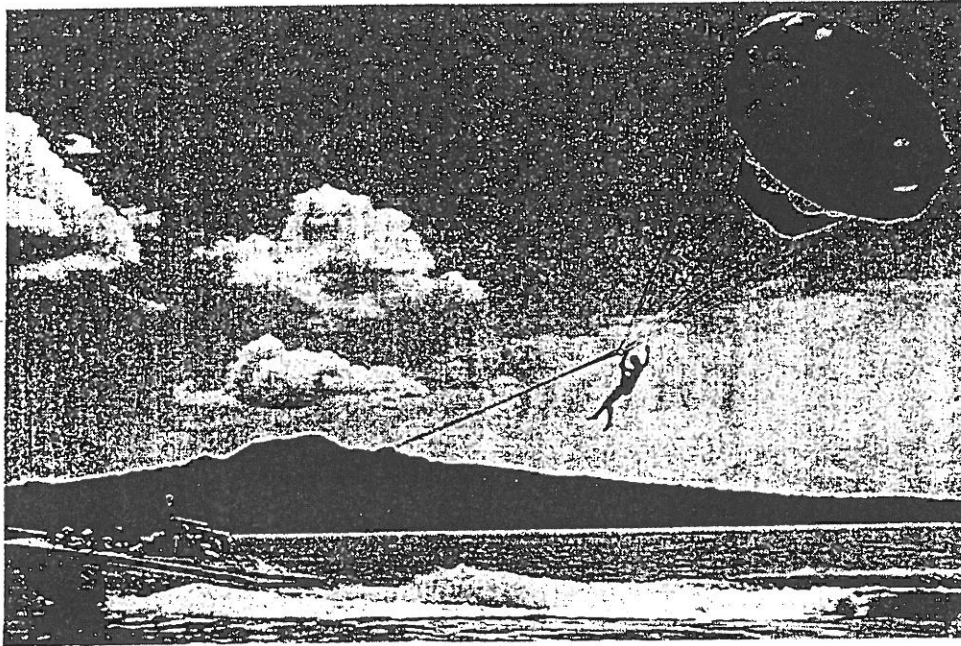
1. The paper consists of 10 questions. Attempt all questions.
2. The marks for each question are not equal and vary from 10 to 15. The total marks aggregate to 120. Candidates are advised to invest their time in proportion to the marks indicated.

DATA WHICH MAY BE REQUIRED

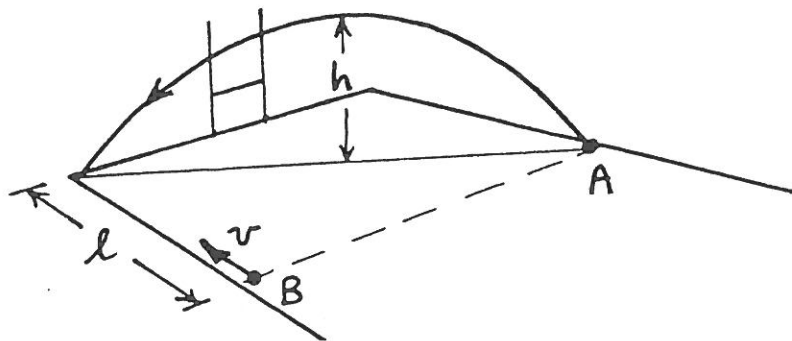
Acceleration of gravity	g	=	9.80 m s^{-2}
Permittivity of free space	ϵ_0	=	$8.85 \times 10^{-12} \text{ F m}^{-1}$
Permeability of free space	μ_0	=	$4\pi \times 10^{-7} \text{ H m}^{-1}$
Electronic charge	e	=	$1.60 \times 10^{-19} \text{ C}$
Planck's constant	h	=	$6.63 \times 10^{-34} \text{ J s}$
Speed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

Question 1. [11 marks]

- (a) The picture below shows a speedboat towing a swimmer hitched to a parachute. The diagram shows the angles of the relevant forces. The swimmer's mass is 55 kg.



- (i) Determine the tension in the tow rope. [4 marks]
- (ii) Given that the boat's speed is 12 m s^{-1} , calculate the additional power required of the boat engine to perform this task. [2 marks]
- (b) In a football match player A kicks a high ball from a side line position to the far corner of the field. Player B, at speed v , is to run down the sideline, catch the ball, and score. Players A and B are each distant l from the goal line, as shown, and B is running the instant A kicks.

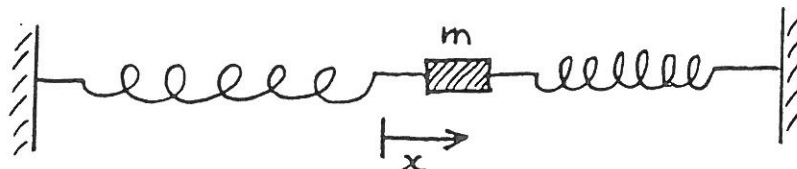


Show that, if the player's heights and the air resistance of the ball are ignored, the ball must reach height h , and no higher, where h is given by

$$h = l^2 \frac{g}{8v^2} \quad [5 \text{ marks}]$$

Question 2. [10 marks]

- (a) When mass m is displaced distance x from its equilibrium position on the 'frictionless' track it is subject to a restoring force of magnitude kx , where the spring constant, k , represents the combined effect of the two springs.



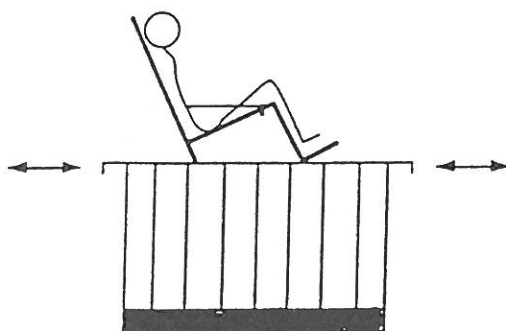
- (i) Briefly explain why the equation of motion for m is

$$ma = -kx \quad [2 \text{ marks}]$$

- (ii) Show that the period of oscillation is given by

$$T = 2\pi\sqrt{m/k} \quad [2 \text{ marks}]$$

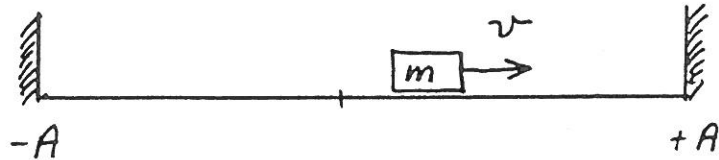
- (b) In the weightlessness of space astronauts cannot use bathroom scales to determine their mass. One alternative technique is to sit strapped into a light chair which is attached to the free ends of a stack of flexible metal strips (saw blades). When displaced the chair oscillates with simple harmonic motion.



Astronaut 'A', mass m , sits on the chair and oscillates with period $T = 2.500\ 000$ s. After drinking a litre of water (mass 1 kg) the period is 2.517 050 s. Determine m assuming the mass of the chair is negligible. [3 marks]

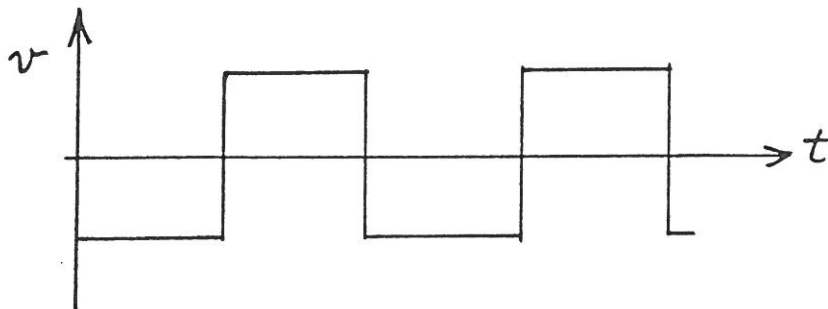
Question 2 continued over the page

- (c) A new oscillator is made by completely removing the springs in (a) and placing perfectly elastic walls on the track at displacements $-A$ and $+A$, measured from the midpoint.



Losing no energy, the mass m with constant speed v moves back and forth along the track, bouncing off one wall then the other, and so on.

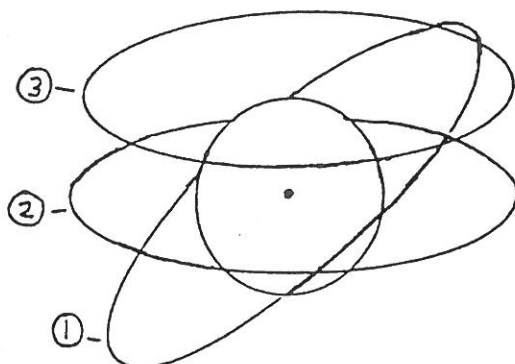
The v/t graph for the motion is:



- (i) Copy this into your answer book and sketch, above it, the x/t graph and below it the a/t graph. Assume $x = 0$ @ $t = 0$. [2 marks]
- (ii) The period, T , now depends upon the amplitude, A . Assuming a velocity v write an equation for the time for one cycle. [1 mark]

Question 3. [12 marks]

- (a) Carefully distinguish between centripetal force and centrifugal force. [2 marks]
- (b) Three circular rings around earth are sketched below. Explain why ① and ② are possible stable satellite orbits but ③ is not. [2 marks]



- (c) A satellite is to be placed in space such that it is always directly above a point on the earth's surface. This is technically convenient because a communications dish on earth can, after alignment, be set in concrete; no tracking mechanism is required.

- (i) Argue that the satellite's orbit must lie in the plane of the equator, like orbit ② above. [2 marks]

- (ii) Given that the equation for the force of gravitational attraction between two masses, M and m , is

$$F = GMm/r^2$$

where G is the gravitational constant, argue that the equation governing all circular satellite orbits is therefore

$$m\omega^2 r = GMm/r^2$$

Here, r is the radius of the satellite's orbit measured from the earth's centre and M and m are the earth and satellite masses, respectively. [1 mark]

- (iii) Show that ω for a '24 h' satellite is $7.27 \times 10^{-5} \text{ rad s}^{-1}$. [1 mark]

- (iv) Given that

$$G = 6.67 \times 10^{-11} \text{ Nm}^2 \text{ kg}^{-2}$$

$$M = 5.98 \times 10^{24} \text{ kg}$$

show that r , for the 24 h satellite, is $4.22 \times 10^7 \text{ m}$. [2 marks]

- (v) On the equator (latitude 0 deg), a dish linking with such a satellite — assumed in an overhead position — would point straight up. But as one proceeds further South or North, the dish must be tilted off the vertical to maintain the link. Eventually, at a large enough latitude, the dish is pointed at the horizon; for latitudes higher than this (Antarctica) communication with the satellite is poor.

Use $R_{\text{EARTH}} = 6.64 \times 10^6 \text{ m}$ to determine the limiting latitude and illustrate with a sketch. [2 marks]

Question 4. [15 marks]

- (a) (i) When two objects (1,2) collide the total linear momentum is conserved. Show that this result is a consequence of Newton's second and third laws, which are, respectively:

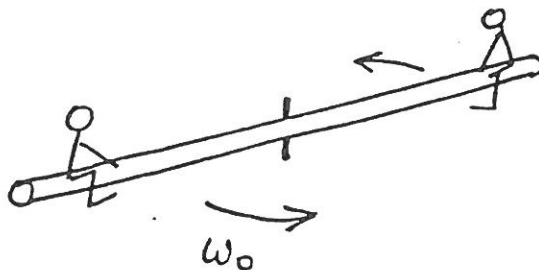
$$F = \Delta p / \Delta t$$

$$F_{12} = -F_{21}$$

[3 marks]

- (ii) An 80 kg astronaut with a 0.5 kg spanner is working on the engines of a space ship, which is drifting through space with a constant velocity. The astronaut, without thinking, and without a safety rope, pushes against the ship and drifts away. He finally manages to stop 30 m behind the ship — but his gas thruster is exhausted. The only way to return to the ship is to throw the spanner directly away from the ship. If he throws the spanner with a speed of 20 m s^{-1} , how long does it take the astronaut to reach the ship? [3 marks]

- (b) Two children, each of mass M , sit on opposite ends of a thin rod of length l and mass M , the same as each child. The rod rotates in the horizontal plane about its midpoint.



- (i) Given that the moment of inertia of the rod alone, through its centre, is $Ml^2/12$, write an expression for the moment of inertia of the rod plus children about the rod's centre. [1 mark]
- (ii) Write an expression for the angular momentum of the system if it rotates with angular frequency ω_0 . [1 mark]
- (iii) While the system is rotating the children pull themselves toward the centre of the rod until they are half as far from the centre as before. Show that the angular speed is now $\frac{14}{5}$ times faster. [4 marks]
- (iv) Show that, after the children have moved, the kinetic energy of the system has increased. (The expression $KE = L^2/2I$, where L is the angular momentum and I is the moment of inertia, is useful here). [2 marks]
- (v) Explain how work has been done on the system to effect the increase. [1 mark]

Question 5. [10 marks]

- (a) It could be said that some laws of physics are actually statements about the geometry and symmetry of space. That is, the form of the laws is pretty much as one would expect. Consider, for example, an isolated 'source of influence' — such as a 'point' charge — and the space around it into which its influence extends, or radiates. Imagine you view the source from different directions, or rotate it.

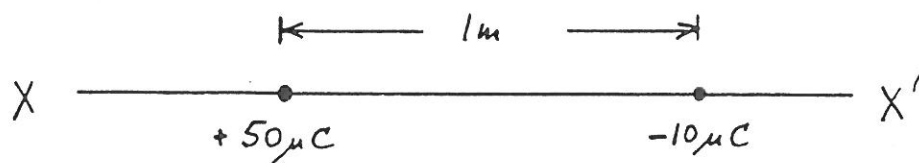


- (i) Explain why the symmetry of space, and of the point source, require that the electric field lines radiate straight out of, or into, the source. [2 marks]
- (ii) Coulomb's law describes how this force field varies with distance for point charges:

$$E \propto \frac{1}{r^2}$$

Argue that this expression is consistent with the formula for the area of a sphere. [2 marks]

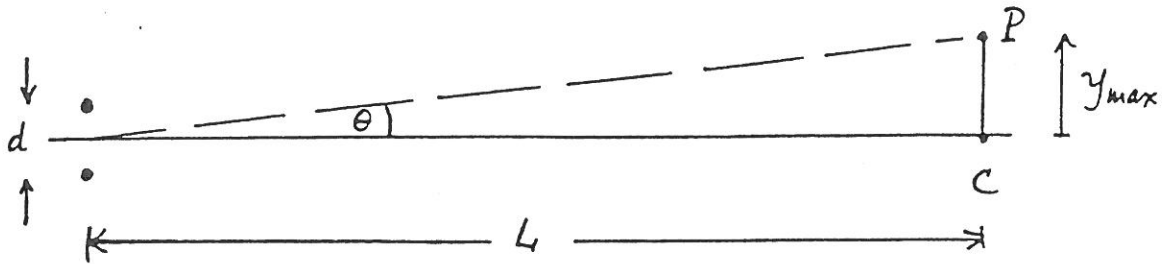
- (b) Two small spheres (effectively points) carry charges of $+50 \times 10^{-6} \text{ C}$ and $-10 \times 10^{-6} \text{ C}$ as shown below. They are 1.0 m apart and XX' is the line through them.



- (i) There is one point on XX' , not at infinity, where the electric field due to these two charges is zero. Show that it is 0.809 m from the $-10 \mu\text{C}$ charge and indicate in a sketch its location. [2 marks]
- (ii) If 100 lines of force are drawn leaving the $+50 \mu\text{C}$ charge in a uniform pattern how many of these will end on the $-10 \mu\text{C}$ charge? [1 mark]
- (iii) Where do the remaining lines terminate? [1 mark]
- (iv) Guided by your answers above, sketch the pattern for the lines of force around the charges. [2 marks]

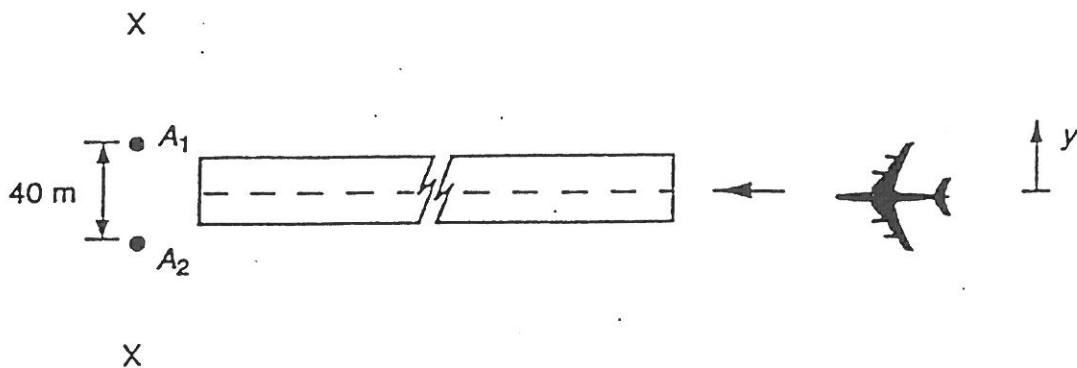
Question 6. [12 marks]

- (a) Identical continuous coherent waves, wavelength λ , are emitted from two (point) sources separation d , as shown.



Point C is a relatively large distance, L , from the sources and P is a point displaced sideways, by distance, y_{max} , and by angle, θ . The signal at P is a maximum and there are no other maxima between P and C .

- Argue that the path difference between the rays to P from the two sources is $d \sin \theta$ and deduce that $y_{max} \approx \lambda L / d$. [3 marks]
 - Argue that there are other points of maximum amplitude at distances $\pm 2 y_{max}$, $\pm 3 y_{max}$, etc, from C . [1 mark]
 - Suppose the source emitted two wavelengths. State where you could place a receiver so that it would receive a maximum from both signals. [1 mark]
- (b) Aircraft are guided to a landing at a foggy airfield using the interference pattern from two vertical wire radio aerials, A_1 and A_2 , spaced 40 m apart, and emitting identical coherent waves of 30 MHz. The aerials radiate equally to all points of the compass. The figure below illustrates.



- Calculate the wavelength of the radiowaves. [1 mark]

Question 6 continued over the page

- (ii) Explain how an aircraft, suitably equipped, could be guided to a safe landing down the runway. [1 mark]
- (iii) Explain how the aircraft could also be guided to an unsafe landing! [1 mark]
- (iv) It is possible to indicate to the pilot that she/he is certainly on the correct path, by transmitting not one but two frequencies, from each aerial, and equipping the aircraft with two radios appropriately tuned. Explain how this would work. [1 mark]
- (v) Why is it important that the two frequencies are not simply related, like the ratio of two integers? (For example, a ratio $f_1/f_2 = 3/4$ would be unwise.) [1 mark]
- (vi) What would be the effects on the system's effectiveness of adding more identical aerials (two are marked X in the figure), also at a regular spacing of 40 m, and carrying the same signals? [2 marks]

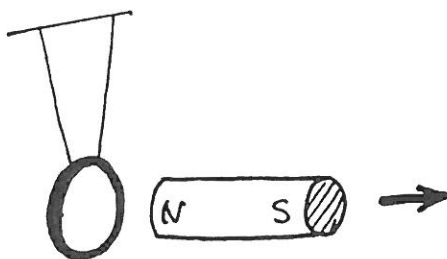
Question 7. [12 marks]

(a) Two powerful statements governing electromagnetic induction are:

- (1) Faraday's law of induction
- (2) Lenz's law.

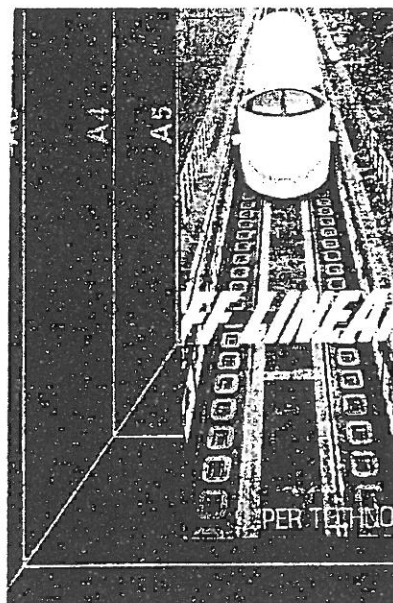
The first relates to changing magnetic fields, the second to induced currents.

State these laws and describe how each relates to the example of a bar magnet being pulled away from a suspended metallic ring, as shown below. That is, as the magnet moves what happens to the ring, and why? [3 marks]



(b) The Japanese 'Maglev' fast train floats above the 'track' using six large and very strong permanent magnets, located under the floor, three down each side of the carriage. The field direction is vertical. (A separate magnetic system propels the vehicle.)

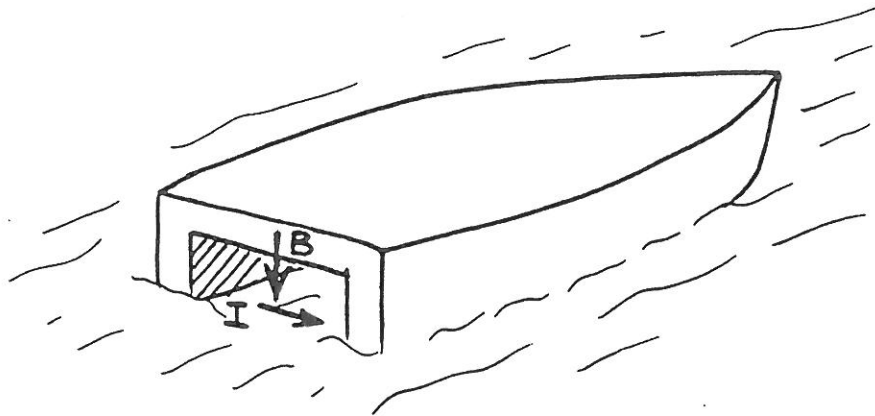
The 'track rails' consist of thick copper loops, 'square rings' — see photo. The metal loops are closed and not connected to anything. They are simply bolted to the concrete base. The train runs on wheels on ordinary rails until it gathers sufficient speed to lift.



- (i) Why does the carriage lift and why does speed matter? [3 marks]
- (ii) Would this system also retard the intended motion; that is, is there an associated drag force, as well as the lift? Explain. [1 mark]

Question 7 continued over the page

- (c) A new magnetically-propelled sea-going ship has a split hull, like a catamaran. A large current, carried by the salt water, is passed between the sides of the hull. A strong magnetic field, from a magnet on the boat, is maintained in the vertical sense through the current-carrying region.

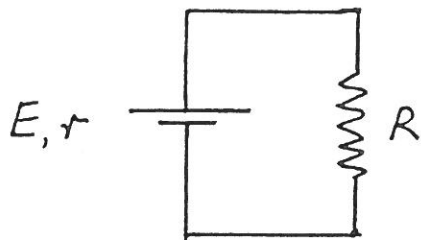


In the stern view above the directions of current I and magnetic field B are shown.

- (i) Explain how the 'motor' propels the ship. [2 marks]
- (ii) For the case shown would the ship move forward or backward? [1 mark]
- (iii) Estimate the current required for a 5000 N force given that the magnetic field, over the 2 m gap, averages 2.3 T. [1 mark]
- (d) Because of recent physics discoveries we hear the word 'superconductor' more often these days. In fact, the train in (b) and the boat in (c), above, use these materials. In one sentence state a property that makes an electrical conductor 'super'. [1 mark]

Question 8. [11 marks]

- (a) A battery has emf E and an internal resistance r . When a 5.0Ω resistor is connected across the terminals the current is 0.5 A .



When the resistor is replaced by an 11.0Ω resistor the current is 0.25 A .

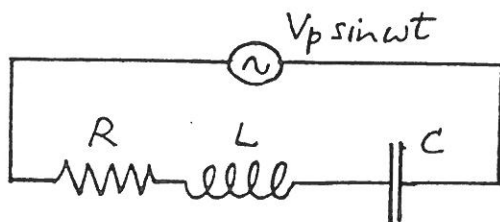
Determine the values of E and r .

[3 marks]

- (b) A $5 \mu\text{F}$ capacitor is charged to 30 V and then connected across a 10 mH inductor of negligible resistance.



- (i) Calculate the energy stored in the capacitor. [2 marks]
- (ii) Calculate the maximum current in the LC circuit. [2 marks]
- (c) A generator, peak voltage V_p , angular frequency ω , and of negligible impedance, is connected across an R, L, C circuit, as shown.



If ω is adjusted to the resonant frequency what, in terms of the circuit symbols, are:

- (i) the peak current? [1 mark]
- (ii) the peak rate of energy dissipation in the circuit? [1 mark]
- (iii) the peak voltage across the inductor? [2 marks]

NOTE: Ohm's law for a series RLC circuit is:

$$V = IZ \quad \text{where} \quad Z = \sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}$$

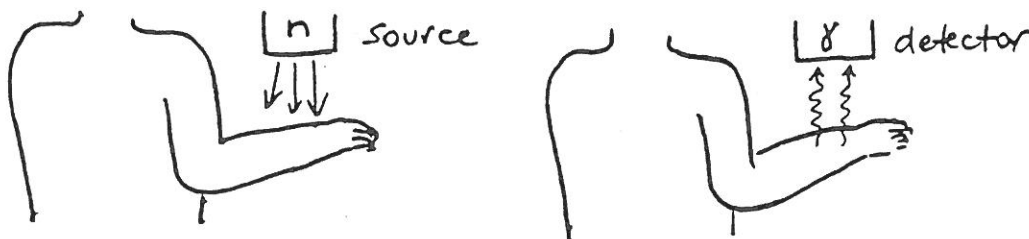
Question 9. [12 marks]

(a) In a simulation of radioactive decay a bucket containing five hundred, twelve-sided dice is shaken and thrown on to a table. All dice with a six-face uppermost are removed from the table and the remainder put in the bucket, shaken again and the process repeated.

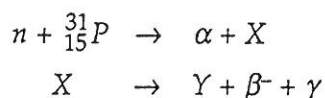
(i) What is the probability for a six-face showing after a throw with just one twelve-sided dice? [1 mark]

(ii) How many of the five hundred dice would you expect to put back in the bucket after the seventh throw? [2 marks]

(b) The solidarity of a person's bone can be assessed by placing a limb — usually an arm — in a neutron beam and irradiating for a minute. The source is then removed and the strength of the γ -ray activity measured. This activity is due to neutron capture by phosphorus in bone.



The nuclear reactions are:



(i) Identify nuclei X and Y. The piece of periodic table shown below will enable you to put a name to the elements. [4 marks]

Z	Element
11	Na sodium
12	Mg magnesium
13	Al aluminum
14	Si silicon
15	P phosphorus
16	S sulfur
17	Cl chlorine
18	Ar argon

(ii) How is it that a neutron can pass through many centimetres of most materials while an α particle, with comparable energy, will only travel through a millimetre, or less? [1 mark]

Question 9 continued over page

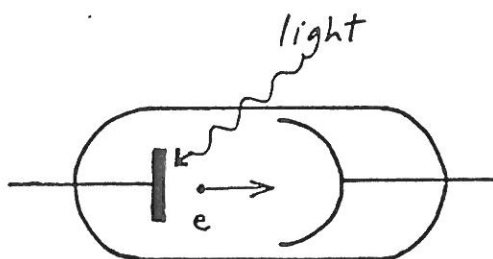
(c) At the top of the earth's atmosphere the radiant energy received directly from the sun, per second, per square metre, is 1360 J.

(i) If the earth-sun distance is 1.50×10^{11} m show that the sun's radiated power is 3.85×10^{26} W. [2 marks]

(ii) Given that the velocity of light is 3×10^8 m s⁻¹ use Einstein's mass-energy equation to calculate the mass lost by the sun per second. [2 marks]

Question 10 [15 marks]

- (a) (i) Sketch a graph to show how the maximum kinetic energy of photoelectrons ejected from a metal surface depends upon the frequency of the incident light. [3 marks]



- (ii) For a certain cathode material used in a photoelectric experiment stopping potentials of 3.0 V, for light of wavelength 300 nm, and 1.0 V for 600 nm light were required, respectively.

Given that $1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$ determine the value of Planck's constant.

[4 marks]

- (iii) What is the dependence, if any, of the stopping potential on light intensity?

[1 mark]

- (b) (i) For what do the letters LASER stand? [1 mark]

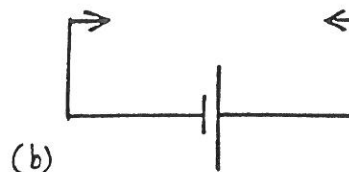
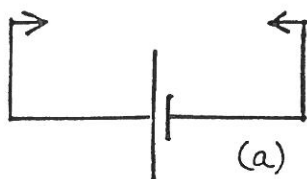
- (ii) Laser light is often intense and of high colour purity; it is also very damaging to the eye. Apart from intensity what is the property of a laser beam that makes it so dangerous to look into? [1 mark]

- (c) Pieces of p type and n type semiconductors are pushed hard together to make a pn junction.



- (i) Sketch the direction of the electric field in the contact region and briefly explain/illustrate why it is so. [2 marks]

- (ii) Which connection, 'a' or 'b' below, would give the greater current flow through the junction, and why? [2 marks]



- (d) A student asks the physics teacher, "What is the velocity of darkness?" Briefly indicate a suitable scientific response. [1 mark]

END OF QUESTION PAPER

