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3220/301

CERTIFICATE OF SIXTH YEAR STUDIES 1997

THURSDAY, 15 MAY
9.30 AM – 12.00 NOON

PHYSICS

Answer **all** questions in **Section A** (35 marks).

Answer **three** questions in **Section B** (45 marks).

Answer **one** question in **Section C** (20 marks).

Any necessary data may be found in the Data Sheet on page two.

Care should be taken not to give an unreasonable number of significant figures in the final answers to calculations.

Square-ruled paper (if used) should be placed inside the front cover of the answer book for return to the Scottish Qualifications Authority.

SCOTTISH
QUALIFICATIONS
AUTHORITY

DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	*Symbol*	*Value*	*Quantity*	*Symbol*	*Value*
Gravitational acceleration	g	$9{\cdot}8\ m\ s^{-2}$	Mass of electron	m_e	$9{\cdot}11 \times 10^{-31}$ kg
Radius of Earth	R_E	$6{\cdot}4 \times 10^{6}$ m	Charge on electron	e	$-1{\cdot}60 \times 10^{-19}$ C
Mass of Earth	M_E	$6{\cdot}0 \times 10^{24}$ kg	Mass of neutron	m_n	$1{\cdot}675 \times 10^{-27}$ kg
Mass of Moon	M_M	$7{\cdot}3 \times 10^{22}$ kg	Mass of proton	m_p	$1{\cdot}673 \times 10^{-27}$ kg
Universal constant of gravitation	G	$6{\cdot}67 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$	Planck's constant	h	$6{\cdot}63 \times 10^{-34}$ J s
Speed of light in vacuum	c	$3{\cdot}0 \times 10^{8}\ m\ s^{-1}$	Permittivity of free space	ε_0	$8{\cdot}85 \times 10^{-12}\ F\ m^{-1}$
Speed of sound in air	V	$3{\cdot}4 \times 10^{2}\ m\ s^{-1}$	Permeability of free space	μ_0	$4\pi \times 10^{-7}\ H\ m^{-1}$

REFRACTIVE INDICES

The refractive indices refer to sodium light of wavelength 589 nm and to substances at a temperature of 273 K.

Substance	*Refractive index*	*Substance*	*Refractive index*
Diamond	2·42	Glycerol	1·47
Glass	1·51	Water	1·33
Ice	1·31	Air	1·00
Perspex	1·49		

SPECTRAL LINES

Element	*Wavelength/*nm	*Colour*
Hydrogen	656	Red
	486	Blue-green
	434	Blue-violet
	410	Violet
	397	Ultraviolet
	389	Ultraviolet
Sodium	589	Yellow

Element	*Wavelength/*nm	*Colour*
Cadmium	644	Red
	509	Green
	480	Blue

Lasers

Element	*Wavelength/*nm	*Colour*
Carbon dioxide	9550 } 10590 }	Infra red
Helium-neon	633	Red

PROPERTIES OF SELECTED MATERIALS

Substance	*Density/* $kg\ m^{-3}$	*Melting Point/* K	*Boiling Point/* K	*Specific Heat Capacity/* $J\ kg^{-1}\ K^{-1}$	*Specific Latent Heat of Fusion/* $J\ kg^{-1}$	*Specific Latent Heat of Vaporisation/* $J\ kg^{-1}$
Aluminium	$2{\cdot}70 \times 10^{3}$	933	2623	$9{\cdot}02 \times 10^{2}$	$3{\cdot}95 \times 10^{5}$	....
Copper	$8{\cdot}96 \times 10^{3}$	1357	2853	$3{\cdot}86 \times 10^{2}$	$2{\cdot}05 \times 10^{5}$	....
Glass	$2{\cdot}60 \times 10^{3}$	1400	....	$6{\cdot}70 \times 10^{2}$	....	....
Ice	$9{\cdot}20 \times 10^{2}$	273	....	$2{\cdot}10 \times 10^{3}$	$3{\cdot}34 \times 10^{5}$	....
Glycerol	$1{\cdot}26 \times 10^{3}$	291	563	$2{\cdot}43 \times 10^{3}$	$1{\cdot}81 \times 10^{5}$	$8{\cdot}30 \times 10^{5}$
Methanol	$7{\cdot}91 \times 10^{2}$	175	338	$2{\cdot}52 \times 10^{3}$	$9{\cdot}9 \times 10^{4}$	$1{\cdot}12 \times 10^{6}$
Sea Water	$1{\cdot}02 \times 10^{3}$	264	377	$3{\cdot}93 \times 10^{3}$	....	....
Water	$1{\cdot}00 \times 10^{3}$	273	373	$4{\cdot}19 \times 10^{3}$	$3{\cdot}34 \times 10^{5}$	$2{\cdot}26 \times 10^{6}$
Air	1·29	....	....	....	....	....
Hydrogen	$9{\cdot}0 \times 10^{-2}$	14	20	$1{\cdot}43 \times 10^{4}$	....	$4{\cdot}50 \times 10^{5}$
Nitrogen	1·25	63	77	$1{\cdot}04 \times 10^{3}$	....	$2{\cdot}00 \times 10^{5}$
Oxygen	1·43	55	90	$9{\cdot}18 \times 10^{2}$	....	$2{\cdot}40 \times 10^{5}$

The gas densities refer to a temperature of 273 K and a pressure of $1{\cdot}01 \times 10^{5}$ Pa.

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SECTION A

Answer ALL questions

Marks

1. A particle moves so that its displacement, in metres, as a function of time, is given by

$$s = 24t - 2t^3.$$

Find

(*a*) the time after the start when the particle momentarily comes to rest and changes direction,

(*b*) the particle's acceleration at this instant,

(*c*) its displacement at this time. **4**

2. A fairground roundabout is shown in Figure 1.

As the roundabout revolves, the poles supporting the chairs for the children swing outwards to a certain angle.

Figure 1

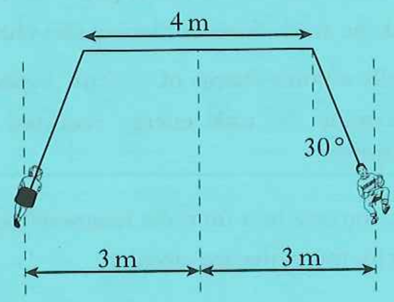

Figure 2

Figure 2 shows a cross-section through the centre, giving the appropriate dimensions.

(*a*) The pole supporting the chair makes an angle of 30° to the vertical.

Calculate the time for each revolution of the roundabout.

(*b*) Does the angle made by the pole with the vertical depend on the mass of the child in the chair?

Give a reason for your answer. **6**

[Turn over

Marks

3. Electric charges are placed in sequence at the vertices of the triangle ABC, shown in Figure 3. The lengths of the sides of the triangle are as shown.

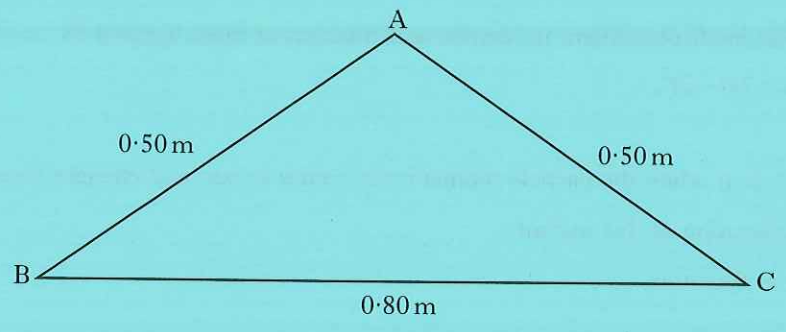

Figure 3

(*a*) A point charge of 4·0 μC is placed at A.
Find the potential at B due to this charge.

(*b*) A point charge of 2·0 μC is placed at B.
Find the work done in placing this charge at B.

(*c*) Finally a point charge of −3·0 μC is placed at C.
Determine the total energy required to assemble these three charges in their respective positions. **6**

4. Electrons, moving in a uniform magnetic field at right angles to the field, follow circular paths. Explain why the paths are circular. **2**

5. The cathode ray tube illustrated in Figure 4 contains two horizontal deflecting plates 40 mm apart.

A uniform magnetic field of $3{\cdot}8 \times 10^{-4}$ T is applied at right angles to the electric field between the deflecting plates.

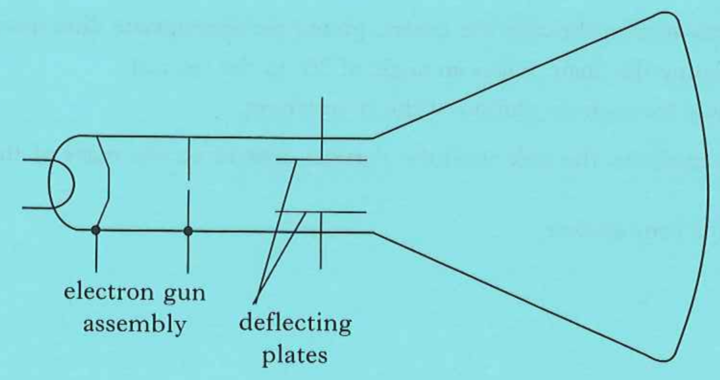

Figure 4

When the potential difference between the deflecting plates is 440 V, the electron beam is **not** deflected.

(*a*) Explain this observation.

(*b*) Calculate the horizontal velocity of the electrons as they pass between the plates.

(*c*) The anode voltage used to accelerate the electrons from rest in the electron gun assembly is 2·5 kV.
Determine the value for the charge to mass ratio (e/m) for the electrons in the beam. **5**

Marks

16. (continued)

(*c*) The $\overline{Q}$ output of a D-type bistable is fed back to the data input D as shown in Figure 22. Clock pulses as shown in Figure 23 are applied to the clock input Clk.

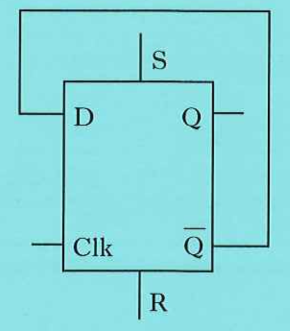

Figure 22

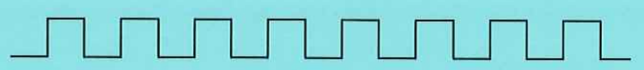

Figure 23

(i) On the square-ruled paper provided, copy the given clock pulse waveform.
Draw the waveform for Q and $\overline{Q}$ below the clock pulse waveform.

(ii) What mathematical operation does this D-type bistable perform?

(iii) In a diagram, show how four such D-type bistables can be connected together to form a 4-bit binary counter.

(iv) Assume that R is taken high to reset each bistable.
Describe, with the aid of a diagram, how this 4-bit counter could be reset automatically after counting to 9. **7**

(*d*) A marker buoy is to have a flashing light which is ON for 1 second then OFF for 3 seconds.

(i) Given a D-type bistable, as shown in Figure 22 above, a 0·5 Hz clock pulse generator and an AND gate, draw a diagram of a system to produce the required timing sequence.

(ii) Sketch waveforms to illustrate the operation of the system. **4**

(20)

[*END OF QUESTION PAPER*]

Marks

16. *DIGITAL ELECTRONICS*

(*a*) (i) Construct a logic diagram, using gates with no more than two inputs, to satisfy the following Boolean equation.

$$Q = A.\overline{B} + \overline{A}.B$$

(ii) Give the truth table for this combination of gates.

(iii) What single 2 input gate would give the same truth table? **5**

(*b*) To process data, decimal numbers often have to be converted to their binary equivalents. Conversion to a 2-bit binary number can be achieved for decimal 0 to 3 using the circuit shown in Figure 21.

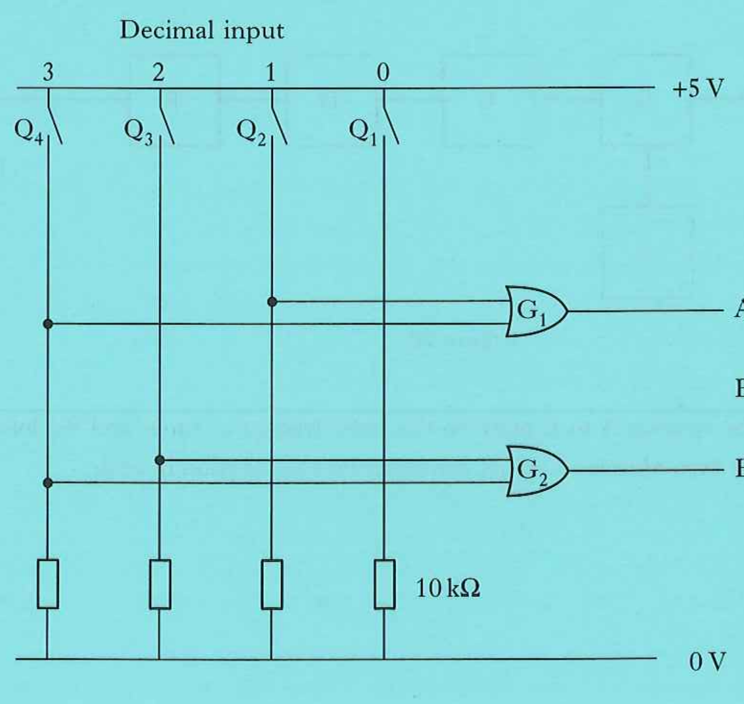

Figure 21

(i) By considering the effect on each of the gates G_1 and G_2, describe the effect on the output of closing in turn the input switches Q_1 to Q_4 which correspond to decimal 0 to 3.

(ii) What is meant by even parity?

(iii) Show how a gate (or gates) can be connected to the outputs A and B to produce the required parity bit. **4**

Marks

6. (*a*) Draw a graph to illustrate the variation in amplitude of sound at a point near to two vibrating tuning forks of slightly different frequencies.

(*b*) Draw a set of graphs which show the relative variation with time of the displacement, velocity and acceleration of a particle moving with simple harmonic motion. **4**

7. The relationship $y = a\sin 2\pi(ft - \frac{x}{\lambda})$ represents a microwave emitted by a transmitter.

The wave strikes a metal plate normally and is reflected.

(*a*) Write down the expression which represents the reflected wave.

(*b*) (i) Derive an expression for the wave resulting from the superposition of the incident and reflected waves.

(ii) Show that this expression now represents a standing wave.

(iii) Find, in terms of λ, the separation of the nodes. **4**

8. Some of the allowed transitions which produce lines in the hydrogen spectrum are shown in Figure 5.

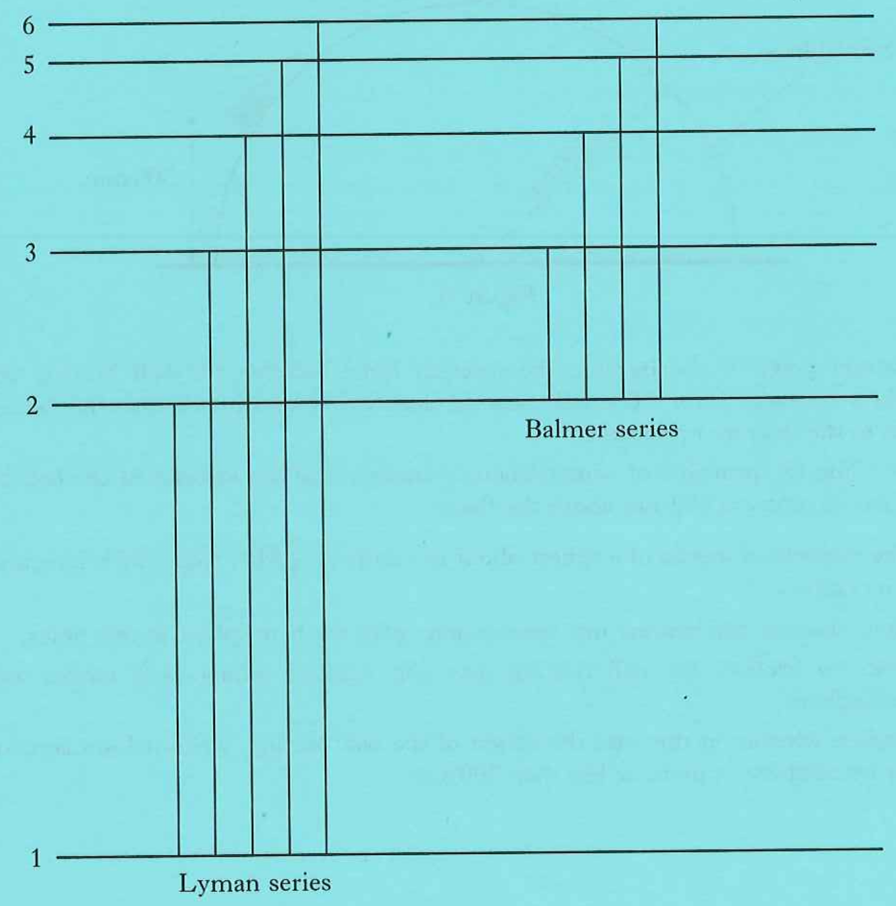

Figure 5

The energy levels of a hydrogen atom are given by the expression

$$E_n = \frac{-me^4}{8\varepsilon_0^{\,2}h^2n^2}.$$

Calculate the longest wavelength of a spectral line in the Balmer series for a hydrogen atom. **4**

(35)

[*END OF SECTION A*]

SECTION B

Answer THREE questions

Marks

9\. (*a*) A particle with an initial angular velocity ω_0 moves with uniform angular acceleration. Show that the equation for its angular displacement θ, after time t, is given by

$$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$$ 3

(*b*) A meteorite of mass 2·0 kg falls from rest towards the earth from a very great distance.

(i) Find the potential energy associated with the meteorite when it is 600 km above the surface of the earth.

(ii) Hence find its speed at this point. 4

(*c*) A ball bearing of radius 10 mm rolls, from rest, without slipping, from the top of a hemisphere. The hemisphere of radius 500 mm rests on the floor as shown in Figure 6.

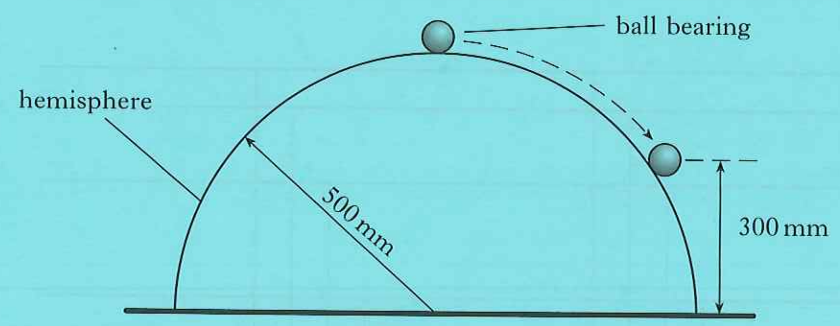

Figure 6

At a certain point in the motion, the reaction force between the ball bearing and the hemisphere becomes zero. The ball bearing therefore loses contact with the hemisphere and falls to the floor as a projectile.

(i) By using the principle of conservation of energy, find the velocity of the ball bearing when its centre is 300 mm above the floor.

The moment of inertia of a sphere about its centre is $\frac{2}{5}Mr^2$, where M is its mass and r is its radius.

(ii) Show that the ball bearing just loses contact with the hemisphere at this point.

(iii) With no friction, the ball bearing may slip without rolling as it moves over the hemisphere.

Explain whether in this case the height of the ball bearing, when it loses contact with the hemisphere, is more or less than 300 mm. 8

(15)

Marks

15. (continued)

(*d*) The normal range of audio frequencies to be carried by a radio signal is 50 Hz to 8 kHz. Radio Scotland broadcasts on a frequency of 810 kHz in the medium waveband.

(i) What are the frequency limits in both the upper and lower sidebands?

(ii) What is the frequency closest to the Radio Scotland frequency which could be used without danger of "interference"? 3

(*e*) Figure 20 shows a block diagram representing a superheterodyne radio receiver.

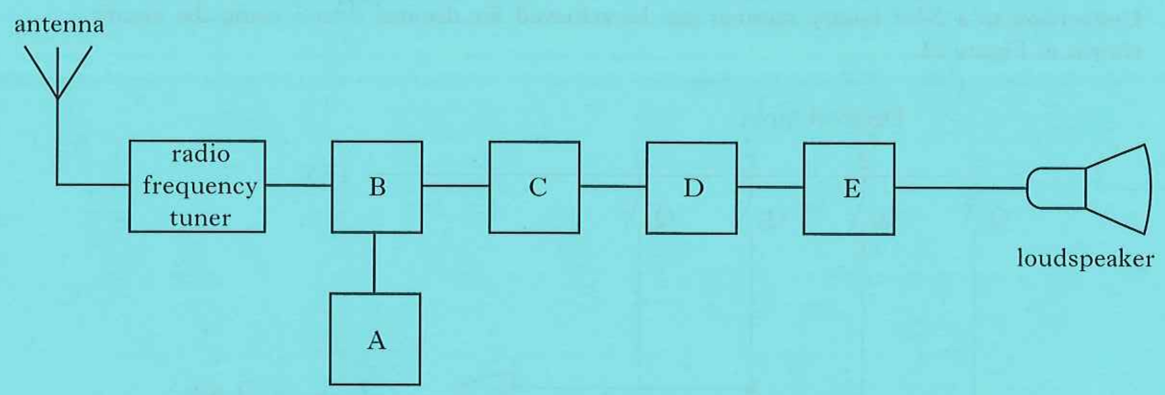

Figure 20

(i) Identify the systems A to E between the radio frequency tuner and the loudspeaker.

(ii) Choose any **two** of these systems and describe the function of each. 5

(20)

[Turn over

15. *RADIO COMMUNICATION*

(*a*) Figure 18 shows a diagram of a parallel LC circuit which is used to investigate electrical oscillations.

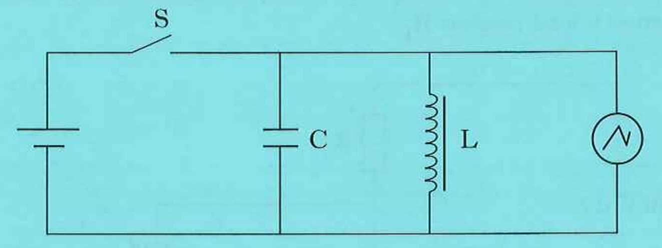

Figure 18

Switch S is opened after being closed for a short time.

(i) On the square-ruled paper provided, draw the trace which would be obtained on the cathode ray oscilloscope screen.

(ii) A resistor is added to the LC circuit.

On new axes, using the same scale, draw the trace which would be obtained on repeating the experiment.

(iii) The number of turns of wire on the inductor L is increased.

On new axes, using the same scale, draw the trace which would be obtained on repeating the experiment.

(iv) Describe how the oscillations in the LC circuit could be maintained. **4**

(*b*) In the tuned circuit of a simple radio, the capacitance can be varied between 100 pF and 500 pF and the coil has an inductance of 2·5 mH.

Calculate the highest resonant frequency for this circuit. **2**

(*c*) (i) Explain, with reference to an electromagnetic wave, what is meant by plane-polarisation.

(ii) Figure 19 shows a half-wave dipole and a polar diagram showing the directional properties of the dipole.

Figure 19

Draw a diagram of an aerial, including a reflector and director, and its corresponding polar diagram.

(iii) A listener may receive signals for a particular channel from two different transmitters broadcasting on the same frequency.

Explain the benefit of the transmitted signals being polarised differently, one horizontally and one vertically. **6**

10. (*a*) State Coulomb's Law for the force between two point charges.

Hence derive the expression $\dfrac{Q}{4\pi\varepsilon_0 r}$ for the electrostatic potential at a distance of r metres from a point charge of Q coulombs. **4**

(*b*) A small sphere of radius 20 mm carries a charge of 30 nC as shown in Figure 7.

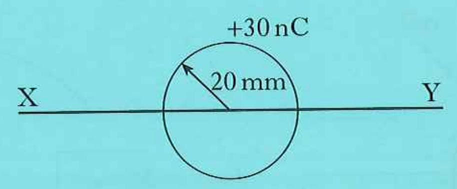

Figure 7

(i) Calculate the potential of the sphere.

(ii) On the square-ruled paper, draw a graph to show the variation of potential along the line XY.

Numerical values should be given on both axes.

(iii) The small sphere is surrounded by a concentric sphere of radius 50 mm which is earthed. This causes a charge of –30 nC to be induced on it as shown in Figure 8.

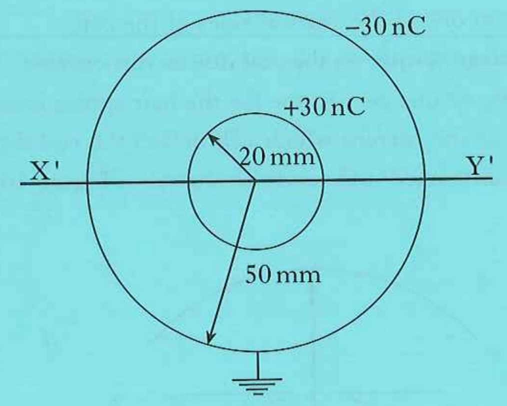

Figure 8

Determine the new potential of the small sphere **after** it is surrounded by the outer sphere.

(iv) Using the same scale, draw another graph to show the variation of potential along the line X'Y' through the common centre of the spheres. **7**

(*c*) The following relationships concern a charged particle moving at relativistic velocity.

The symbols have their usual meanings.

$$m_0c^2 + qV = mc^2 \qquad m = \frac{m_0}{\sqrt{\left(1 - \frac{v^2}{c^2}\right)}}$$

(i) Determine the velocity to which an electron would require to be accelerated for its relativistic mass to equal four times its rest mass.

(ii) The electron acquires this velocity by being accelerated across a potential difference. Find the value of this potential difference. **4**

(15)

Marks

11. (*a*) The diagrams in Figures 9(*a*) and 9(*b*) represent two views of a centre zero moving coil meter.

The coil contains 150 turns of wire on a square frame of side 20 mm. It is situated in a uniform magnetic field of $2{\cdot}4 \times 10^{-2}$ T and can rotate about a vertical axis as shown in Figure 9(*a*). The hair springs at each end apply a restoring torque to the coil in direct proportion to the angle through which the coil is deflected.

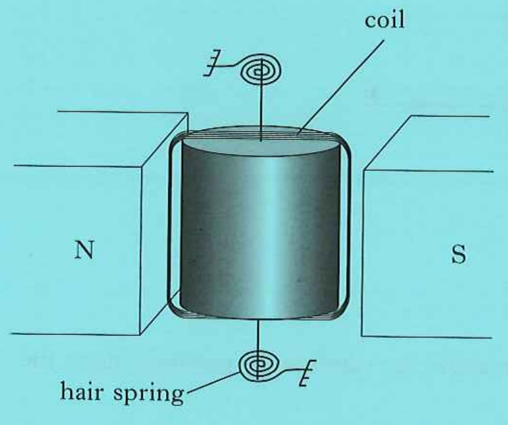

Figure 9(*a*)

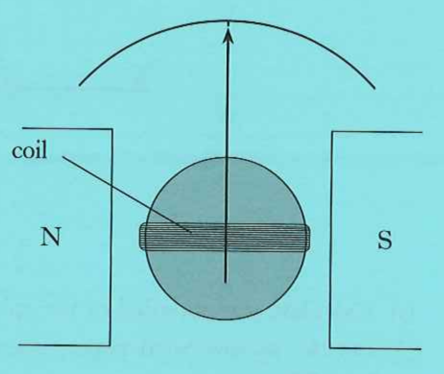

Figure 9(*b*)

A current of 2·0 mA in the coil causes it to be deflected through an angle of 20°.

(i) Calculate the force on one of the vertical sides of the coil.

(ii) Calculate the deflecting torque on the coil due to this current.

(iii) What is the restoring torque per degree for the hair spring arrangement?

(iv) Calculate the value of the current which will deflect the coil through 40°.

(v) Another meter is constructed differently as shown in Figure 10.

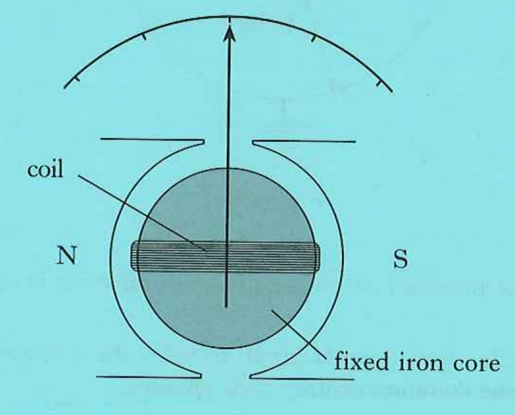

Figure 10

Explain why the scale on this meter is linear. **8**

Marks

14. (continued)

(*d*) The power supply for electronic equipment is often regulated by using a Zener diode to produce a constant output voltage.

The circuit, given in Figure 17, shows how a Zener diode can be used to produce a constant voltage across a load resistor R_L.

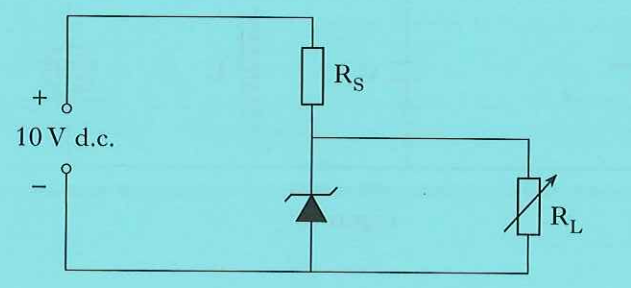

Figure 17

(i) Sketch the current-voltage characteristic for a typical Zener diode.

(ii) With reference to your graph, explain how a constant voltage is produced.

(iii) The resistance of R_S is 150 Ω and the breakdown voltage of the Zener diode is 6·2 V. Calculate the maximum current in the Zener diode.

(iv) Calculate the theoretical minimum resistance of R_L across which the output voltage is stabilised at 6·2 V.

(v) Draw a diagram of a circuit, including a transistor, which allows a much greater current in the load resistor R_L. **8**

(20)

[Turn over

Marks

14. *ANALOGUE ELECTRONICS*

(*a*) (i) A sinusoidal voltage given by $V = V_0 \sin 2\pi ft$ is applied to a capacitor.

Derive the expression for the reactance X_c of the capacitor.

(ii) A 100 μF capacitor is joined in series to a 100 Ω resistor.

Determine the frequency at which the impedance of the combination is 200 Ω. **4**

(*b*) (i) Distinguish between positive and negative feedback.

(ii) Negative feedback in an amplifier circuit seems to be an apparent contradiction and yet is used extensively.

State **two** advantages of using negative feedback. **3**

(*c*) The circuit for an RC integrator using an op–amp is shown in Figure 15.

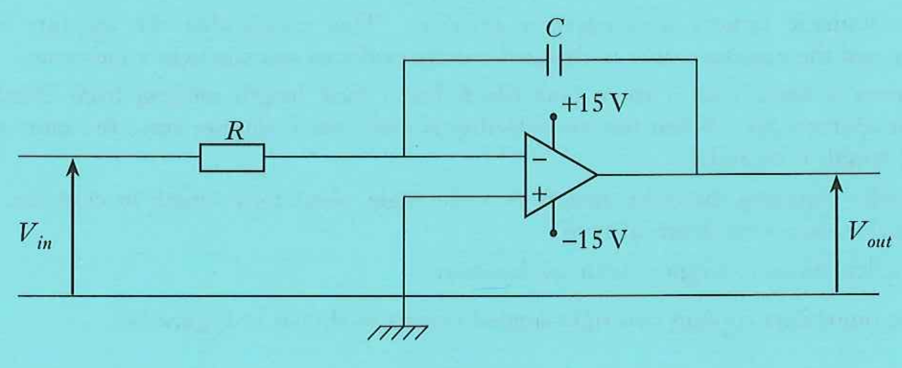

Figure 15

(i) Derive the expression for the output voltage.

(ii) The voltage given in the following graph, Figure 16, is applied at the input of the above circuit where $C = 2\,\mu F$ and $R = 1\,M\Omega$.

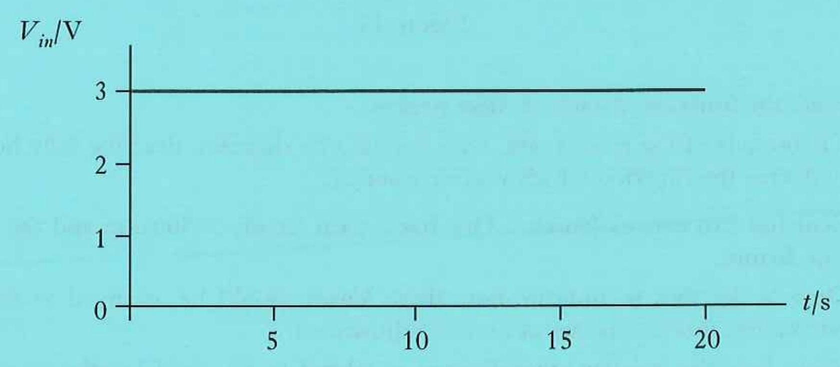

Figure 16

What is the value of V_{out} when $t = 5{\cdot}0$ s?

(iii) Draw a graph, with numerical values on both axes, which shows the variation of V_{out} with time for the first 20 s after the input voltage is applied. **5**

Marks

11. (continued)

(*b*) Two long parallel wires, 120 mm apart, pass vertically through holes in a bench and carry currents of 5·0 A and 1·0 A as shown in Figure 11.

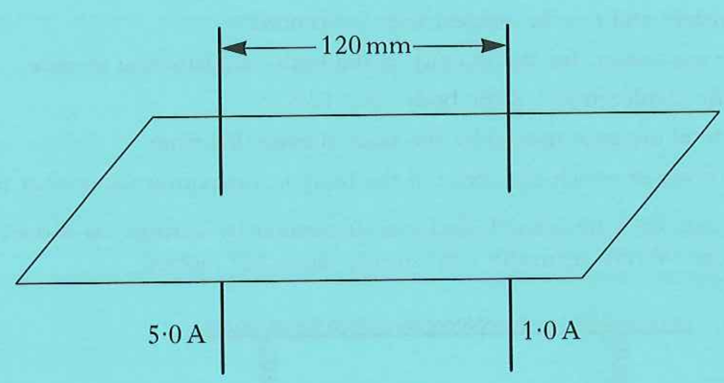

Figure 11

Show, with calculations to justify each answer, that there is a point on the bench where the magnetic induction due to these currents is zero, either 20 mm to the left or 30 mm to the right of the wire carrying the current of 1·0 A. **4**

(*c*) The current in the coils, used to deflect the electron beam in a television tube, varies with time as shown in Figure 12.

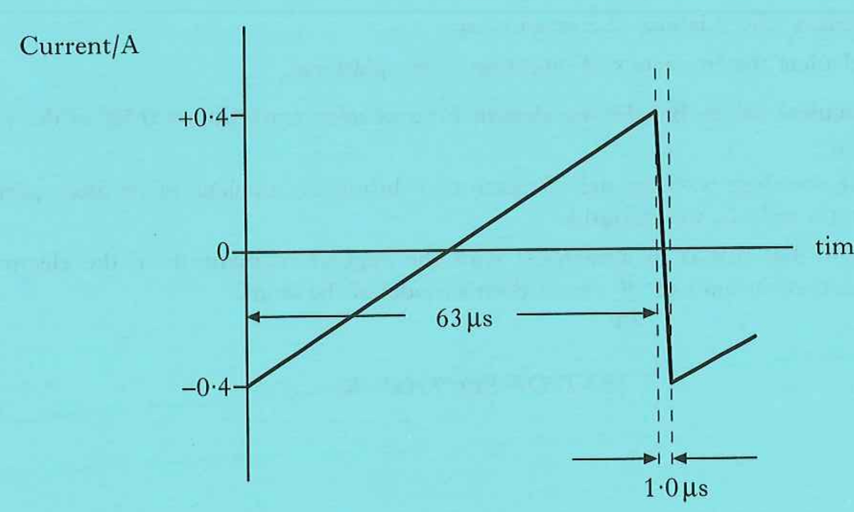

Figure 12

The spot sweeps across the screen from left to right in 63 μs, and then flies back in 1·0 μs.

The self inductance of the coils is 4·5 mH.

Calculate the induced e.m.f. across the coils

(i) during each sweep,

(ii) during each flyback. **3**

(15)

[Turn over

Marks

12. (*a*) A body moves in such a way that its net displacement x, from the origin, is given by the expression

$$x = 4\cos\left(\frac{\pi}{5}t + \frac{\pi}{2}\right)$$

where x is in metres and t is the elapsed time in seconds.

(i) Obtain an expression for the velocity of the body as a function of time.

(ii) What is the displacement of the body after 12·5 s?

Find the total distance moved by the body during this time.

(iii) Find two times at which the speed of the body is a maximum and what this value is. **7**

(*b*) A small mass rests on a horizontal platform suspended by springs, as shown in Figure 13. The platform can vibrate vertically with simple harmonic motion.

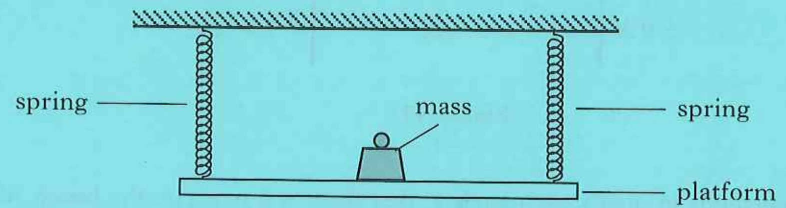

Figure 13

When vibrating with an amplitude of 100 mm, it is found that the mass just loses contact with the platform at the top of its oscillation.

(i) Explain why this loss of contact occurs.

(ii) Calculate the frequency of vibration of the platform. **4**

(*c*) (i) Calculate the de Broglie wavelength for a neutron travelling at 0·5% of the velocity of light.

(ii) The standing wave model of electrons orbiting the nucleus of an atom permits only certain radii or wavelengths.

Show that this is in agreement with the angular momentum of the electrons being quantised in units of $\frac{h}{2\pi}$, as in Bohr's model of the atom. **4**

(15)

[*END OF SECTION B*]

SECTION C

Answer Question 13 OR 14 OR 15 OR 16

Marks

13. *OPTICAL INSTRUMENTS*

(*a*) A dealer in antiques examines the hallmark on a piece of silver using a convex lens of focal length 50 mm. He holds the lens close to his eye and 45 mm from the object.

Draw a ray diagram to show how the image is formed and hence, or otherwise, determine the nature, linear magnification and position of the image he sees. **4**

(*b*) The range of acceptable sharpness of the image produced by a camera lens can be described by either of the following terms: *depth of focus* or *depth of field*.

(i) Distinguish between *depth of focus* and *depth of field*.

(ii) Explain why *stopping down* the lens increases the depth of focus. **3**

(*c*) A semi-automatic camera uses *aperture priority*. This means that the aperture is set manually and the exposure time is changed automatically to suit the light conditions.

The camera is fitted with a zoom lens which has a focal length ranging from 28 mm to 80 mm at aperture *f*/4. When the zoom facility is used, the *f*-number stays the same while the focal length is changed.

Explain why adjusting the zoom lens from wide angle, short focal length to close up, long focal length reduces the depth of field.

Include calculations to support your explanation. **3**

(*d*) Prismatic binoculars contain two right-angled prisms as shown in Figure 14.

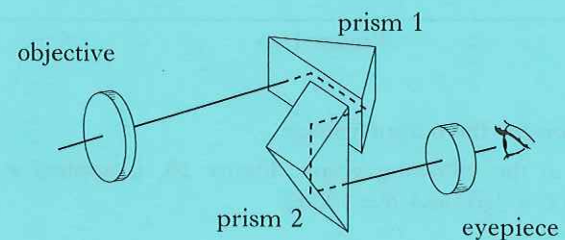

Figure 14

(i) State the function of each of these prisms.

(ii) Choose one of the prisms and, with the aid of a diagram, describe fully how the prism performs the function which you have stated. **3**

(*e*) A student has two convex lenses. One has a focal length of 500 mm and the other a focal length of 20 mm.

(i) Draw a diagram to indicate how these lenses should be arranged to form a simple astronomical telescope set at normal adjustment.

(ii) Show how the angular magnification is related to the focal lengths of the lenses and find its value in this case.

(iii) The exit pupil at normal adjustment is the image of the objective lens which is formed by the eyepiece lens.

Prove that the distance from the eyepiece lens to the exit pupil is given by

$$\frac{f_e(f_e + f_o)}{f_o}$$

where f_o and f_e are the focal lengths of the objective and eyepiece lenses respectively.

(iv) The diameter of the objective lens is 60 mm.

Find the diameter of the exit pupil for the given lenses.

(v) In use, the observer's eye should be positioned at the exit pupil.

State what the observer would see if his eye was

(A) closer to the eyepiece

(B) further from the eyepiece. **7**

(20)