[3220/240] 1986

SCOTTISH CERTIFICATE OF EDUCATION

PHYSICS

Higher Grade—PAPER II

Monday, 12th May—1.30 p.m. to 4.00 p.m.

In SECTION A answer ALL questions.

In SECTION B answer any THREE questions.

In SECTION C answer any ONE question.

Use the approximation $g = 10\,\mathrm{m\,s^{-2}}$ or $g = 10\,\mathrm{N\,kg^{-1}}$.

Any other data required will be found in the Science Data Booklet (1982 edition) provided.

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

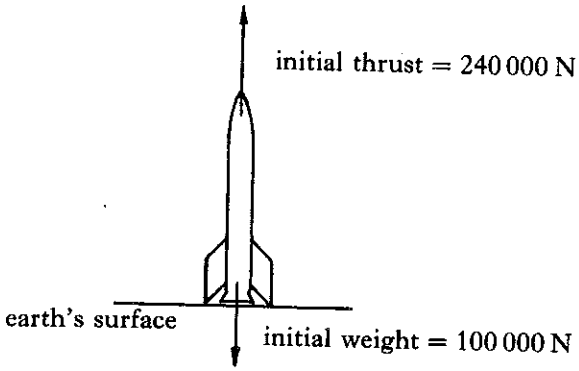
TE&S 3220/240 2/20960

SECTION A

ALL questions in this section should be attempted.

Marks

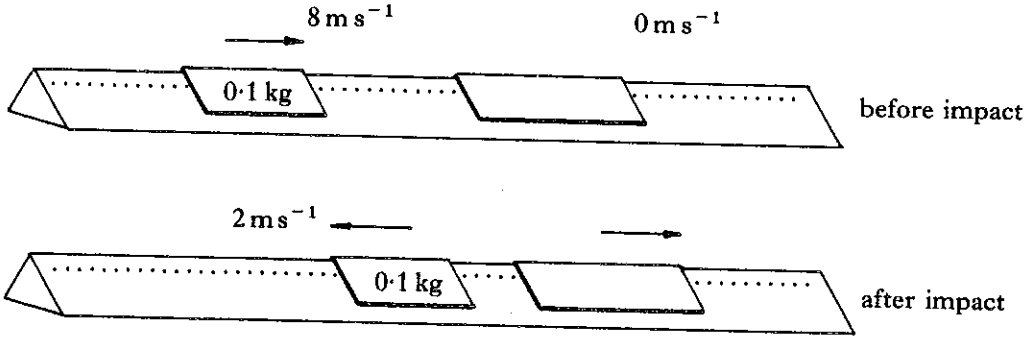
1. A liquid-fuelled rocket is taking-off vertically upwards.



(*a*) What is the initial acceleration of the rocket?

(*b*) Assuming that the burning fuel provides a constant thrust, explain what would happen to the acceleration as the rocket rises. **4**

2. On an air-track a lighter vehicle hits a heavier one and bounces back from it. The mass of the lighter vehicle is 0·1 kg and its speed before the collision is $8\,m\,s^{-1}$. After impact it rebounds at $2\,m\,s^{-1}$.

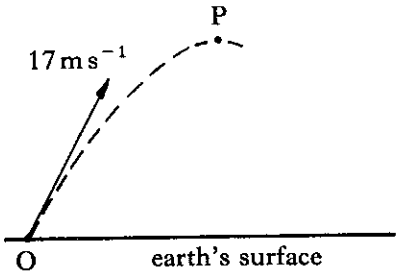


(*a*) Calculate the size of the change of momentum of the heavier vehicle.

(*b*) What additional information would be needed to calculate the average force exerted on the heavier vehicle due to the collision? **3**

Marks

3. A ball is projected from point O with a velocity of $17\,m\,s^{-1}$ as shown.



It reaches its maximum height at P after 1·5 seconds.

Calculate the initial vertical and horizontal components of the velocity of the ball. **3**

4. Three resistors are available. Their values are $4\,\Omega$, $6\,\Omega$, and $12\,\Omega$.

Describe how two, or all three, of the resistors might be combined to give each of the following resistances.

(*a*) $10\,\Omega$

(*b*) $3\,\Omega$

(*c*) $8\,\Omega$ **4**

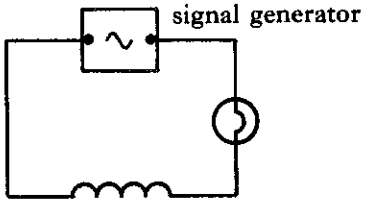
5. You are given a capacitor, a battery, a resistor, a switch, a cathode ray oscilloscope and connecting wires.

You are asked to set up a circuit which would allow you to look at the variation of current as the capacitor is charged up through the resistor.

(*a*) Draw a diagram of your circuit.

(*b*) Draw a sketch to show the variation of current while the capacitor is charging. **3**

6. The circuit shows a signal generator which provides an alternating voltage of constant peak value, a small light bulb and a coil.



(*a*) State what happens to the brightness of the lamp when the frequency of the signal generator is increased.

(*b*) The frequency is kept constant and the coil is straightened out.

Explain what happens to the brightness of the lamp. **3**

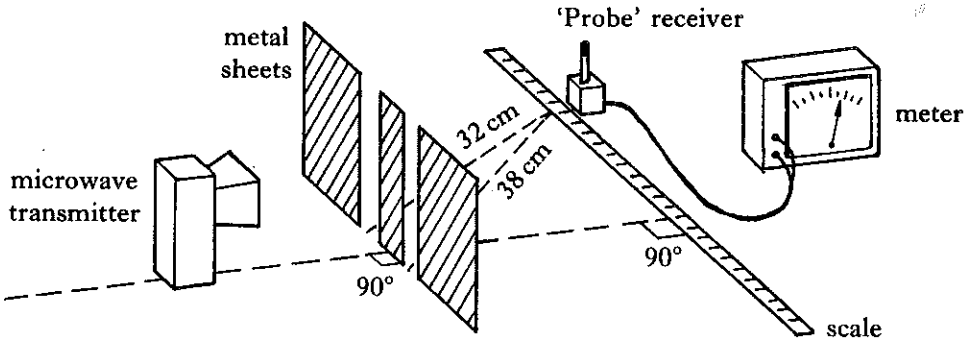
[Turn over

Marks

7. The mass of the helium nucleus ^4_2He is $6{\cdot}642 \times 10^{-27}$ kg.

   Calculate the mass defect and use the relationship $E = mc^2$ to calculate the binding energy of this nucleus. **4**

8. The sketch shows the experimental arrangement used to investigate microwaves passing through a double-slit system.



   As the probe is moved along the scale the meter reading increases and decreases repeatedly.

   (*a*) The probe gives one of its maximum readings in the position shown, 32 cm from one slit and 38 cm from the other.

   Could the wavelength of the microwaves be

   (i) 3 cm

   (ii) 12 cm?

   Give a reason for your answer in each case.

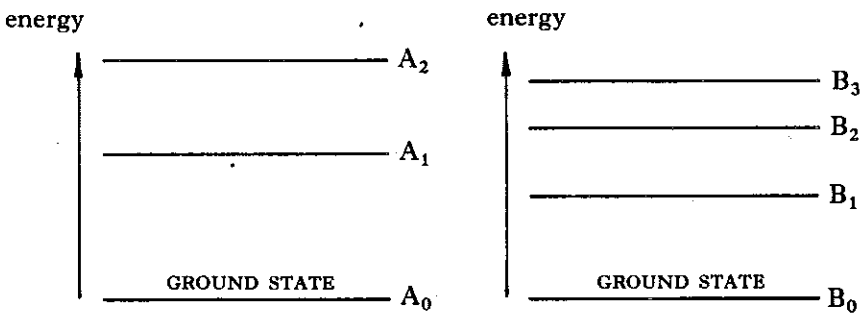
   (*b*) Explain how a minimum reading on the meter occurs. **4**

9. In an experiment to estimate the diameter of a molecule, a small drop of oil is allowed to fall on to a clean water surface.

   The oil spreads out, forming a circular patch assumed to be one molecule thick.

   Describe which measurements are made in this experiment and explain how the diameter of the oil molecule can be estimated. **4**

10. Energy level diagrams for two atoms A and B are shown to the same scale.



   Electrons are excited to levels A_2 and B_3.

   Explain which transition, in which atom, would give rise to the emission of radiation with

   (*a*) the shortest wavelength;

   (*b*) the longest wavelength. **3**

(35)

[END OF SECTION A]

SECTION B

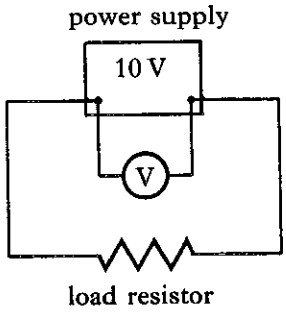
Answer any THREE questions. Each question carries FIFTEEN marks.

Marks

11. (*a*) The resistance R of a resistor and the power P dissipated in the resistor can each be expressed in terms of the voltage V across the resistor and the current I in the resistor.

Show that the power dissipated in a resistor can also be expressed by $P = \frac{V^2}{R}$. **2**

(*b*) The diagram shows a circuit which can be used to find the power delivered to an external (load) resistor. The power supply has an e.m.f. of 10·0 volts and the voltmeter has a very high resistance.



When the load resistor is 4·0 Ω the voltmeter reads only 5·7 volts.

(i) Explain why the voltmeter does **not** read 10·0 volts.

(ii) Show that the power dissipated in the load resistor is 8·1 watts.

(iii) The experiment is repeated using different load resistors and the results are recorded in a table as shown

load resistor	*voltmeter reading*	*power in load resistor*
1·0 Ω	2·5 V	6.25
2·0 Ω	4·0 V	8
4·0 Ω	5·7 V	8·1 W
6·0 Ω	6·7 V	7.98
7·0 Ω	7·0 V	7

(A) Draw a graph of the power dissipated in the load resistor against the resistance of the load resistor.

(B) Deduce from the graph the value of the internal resistance of the power supply. **7**

(*c*) An initially uncharged capacitor is charged using a **constant** current of 90 μA. After 100 seconds the voltage across the capacitor is 12 volts.

(i) How much charge is stored on the capacitor after 100 seconds?

(ii) How much energy is stored in the capacitor after 100 seconds?

(iii) A second capacitor, with a larger capacitance, is charged for the same time using the same current.

(A) How does the voltage across the second capacitor compare with the first?

(B) How does the energy stored in the second capacitor compare with the first? **6**

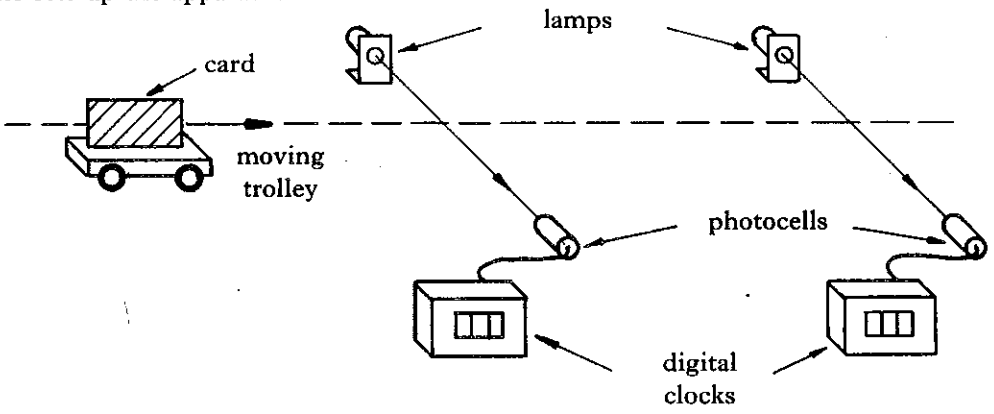
(15)

[Turn over

Marks

12. (*a*) A pupil is asked to measure the average frictional force acting against a trolley as it rolls along a horizontal surface.

She sets up the apparatus shown.



The pupil measures the distance between the two light beams.

(i) What other measurements would she need to take?

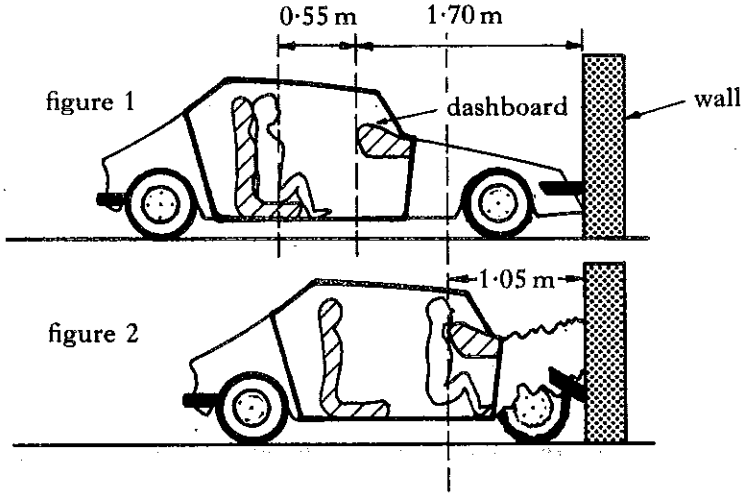
(ii) How would she calculate the deceleration of the trolley using some of these measurements?

(iii) State how the average frictional force would then be calculated. **6**

(*b*) In a test a dummy passenger is placed, without a seat belt, in a car 0·55 m from the dashboard.

The car is made to crash into a rigid wall at a speed of $12\,m\,s^{-1}$.

The front of the car crumples progressively and shortens by 0·65 m before the car comes to rest. The passenger compartment is not damaged.



During the crash the dummy continues forward freely.

(i) At what speed does it hit the dashboard, which has already come to rest?

(ii) How far does the dummy travel, relative to the ground, between the instant when the front of the car first makes contact with the wall (figure 1) and the instant when the dummy first makes contact with the dashboard (figure 2)?

Marks

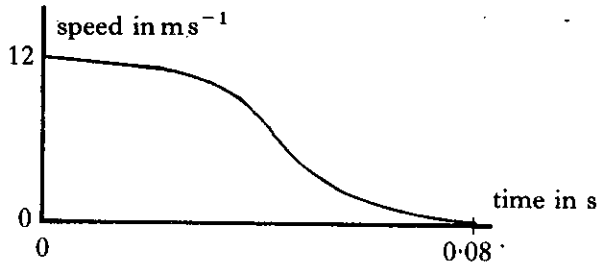
(iii) What time elapses between these two instants?

(iv) The dummy has a mass of 80 kg. The dashboard padding is compressed by 0·080 m in bringing the dummy to rest.

Assuming that all of the dummy's kinetic energy is absorbed by the padding, what average force does the dashboard exert on the dummy?

(v) Many cars are designed, like this one, so that the front crumples progressively on impact. Explain an advantage of this.

(vi) In the test the speed-time graph for the passenger compartment during the collision is as shown.



Describe the deceleration of this compartment during the collision with the wall. **9**

(15)

[Turn over

Marks

13. (*a*) A semicircular perspex block can be used to show the differences in the angles of refraction for different colours of light.

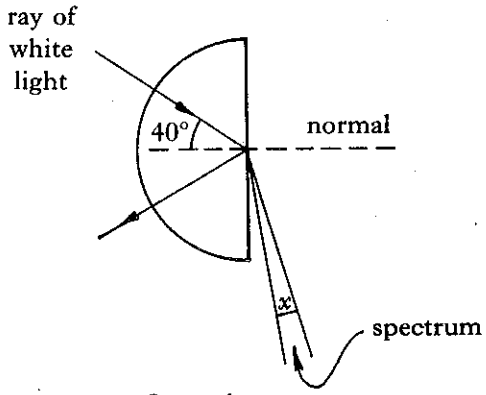


figure 1

(i) Explain how this block could be used to find the values of the refractive indices of perspex for the colours at the limits of the visible spectrum.

(ii) Calculate the value of the angle x between the red and violet rays when the ray of white light makes an angle of 40° as shown in figure 1.

Data for perspex is in Table I.

Table I

colour of light	*refractive index*
red	1·49
violet	1·52

(iii) The values for frequency and wavelength for orange light in air are shown in Table II.

Table II

Frequency	$5{\cdot}09 \times 10^{14}$ Hz
Wavelength	$5{\cdot}89 \times 10^{-7}$ m

The refractive index of perspex for orange light is 1·50.

What are the values of frequency and wavelength for orange light inside the block? **7**

(*b*) The sketch illustrates a method for finding the focal length of a converging lens, using a plane mirror and a small filament lamp.

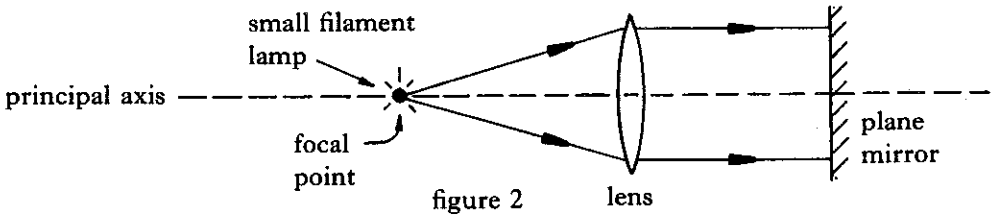


figure 2

The lens-mirror system forms an image of the filament.

(i) Explain where the image is formed when the filament is placed at the focal point of the lens.

(ii) The lamp is moved, along the principal axis, slightly further away from the lens.

Draw the lamp, in its new position, and the lens-mirror system as in figure 2.

Draw rays to show where the image of the filament is now formed. **4**

(*c*) A converging lens is to be used to form a real image with a linear magnification of 2 for a slide placed 18 cm from the lens.

(i) How far is the image from the lens?

(ii) Draw a ray diagram of this arrangement and from it find the focal length of the lens.

State the scale used. **4**

(15)

Marks

14. (*a*) For an ideal gas the pressure is given by the expression $pV = \frac{1}{3}Nm\overline{u^2}$.

(i) State three assumptions made in the model of an ideal gas used in the derivation of this expression.

(ii) Explain what is meant by $\overline{u^2}$.

To illustrate your explanation show how to calculate $\overline{u^2}$ for the following numerical values of u: 4, 8, 9, 10, 12.

(iii) Oxygen, in a closed container of constant volume, is at a pressure P_1.

As a result of an increase in temperature the root mean square speed of the oxygen molecules increases from $200\,m\,s^{-1}$ to $300\,m\,s^{-1}$.

The new pressure of the oxygen is P_2.

Calculate the value of $\frac{P_2}{P_1}$. **7**

(*b*) In the photoelectric effect electrons are emitted from a surface when electromagnetic radiation falls on the surface.

From experiments the following two statements can be made.

1. For any surface no photoemission occurs unless the frequency of the incident radiation is sufficiently high.
2. When the intensity of the incident radiation increases the maximum kinetic energy with which the electrons are emitted does **not** increase.

Explain how these two statements may be justified by thinking of electromagnetic radiation as consisting of particles (photons). **6**

(*c*) Given the relationship $E = hf$, calculate the energy of a photon of light of wavelength $405 \times 10^{-9}\,m$. **2**

(15)

[END OF SECTION B]

[Turn over

SECTION C—SPECIAL TOPICS

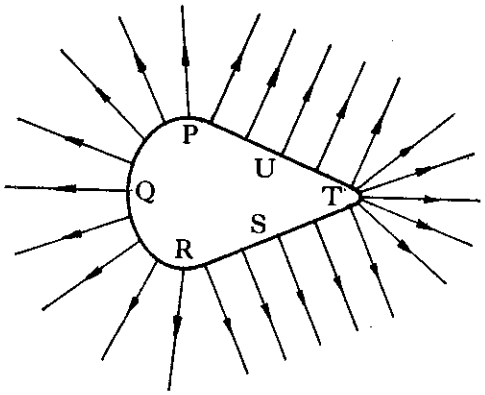
Answer any ONE question. Each question carries TWENTY marks.

Marks

15. *ELECTROSTATICS*

(*a*) A charge is placed on an isolated, conducting sphere.
Sketch the pattern of electric field lines around the sphere. 2

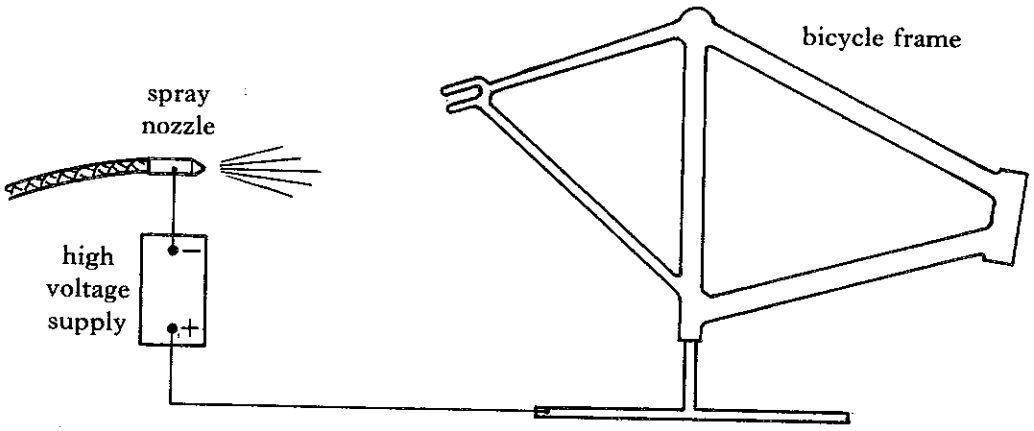
(*b*) The electric field around a pear-shaped conductor is shown in the diagram. The letters P, Q, R, S, T, U refer to points on the surface of the conductor.



(i) Where is the electric field intensity greatest?

(ii) Explain why a conductor of this shape is likely to lose its charge more quickly than a spherical conductor charged to the same potential. 3

(*c*) The diagram illustrates the electrostatic paint spraying of a bicycle frame. The nozzle of the spray gun is connected to one terminal of a high voltage supply and the bicycle frame to the other terminal.

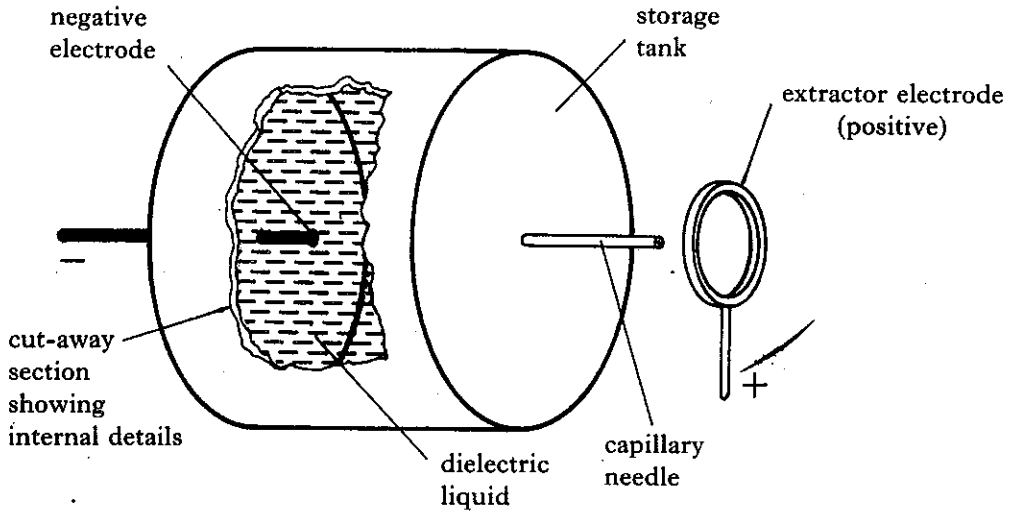


(i) Explain how this electrostatic process works.

(ii) Describe **one** advantage of this process. 5

Marks

(*d*) The diagram shows a type of electric rocket suitable for use in a satellite as a thruster for manoeuvring.



A storage tank containing a dielectric liquid is connected to a capillary needle.

A high potential difference is applied between the extractor (positive) electrode and the negative electrode within the storage tank.

(i) Explain why liquid droplets are projected from the capillary needle. Draw an enlarged diagram showing the tip of the needle to illustrate your answer.

(ii) A droplet of liquid of mass m kilograms and charge q coulombs is accelerated by a potential difference of V volts. Show that the speed gained by the droplet is given by

$$v = \sqrt{\frac{2qV}{m}}.$$

(iii) Calculate the gain in speed of a droplet with a charge-to-mass ratio of $4{\cdot}0 \times 10^4\,C\,kg^{-1}$ when it is accelerated by a potential difference of 25 kV. **8**

(*e*) In the region of space just outside the earth's atmosphere, there exist hazards to the operation of a spacecraft caused by electrostatic phenomena. Describe one such hazard and explain briefly how it might affect the operation of the spacecraft. **2**

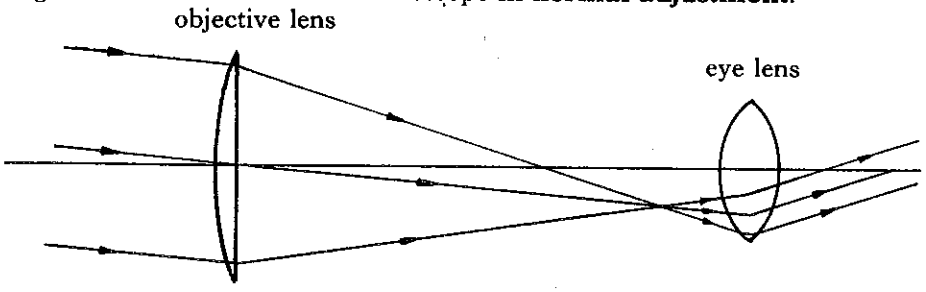
(20)

[Turn over

Marks

16. *OPTICAL INSTRUMENTS*

(*a*) The diagram shows an astronomical telescope **in normal adjustment**.



(i) Explain why the distance between the objective and eye lenses is equal to the sum of their focal lengths in this adjustment.

(ii) The telescope is to be redesigned to give greater angular magnification using the same eye lens and a new objective lens.

Explain how the length of the telescope will be affected. **4**

(*b*) Prismatic binoculars can be described as "a pair of telescopes mounted side by side".

(i) Draw a sketch of **one side** of a pair of binoculars, showing the passage of a single ray of light.

(ii) Describe a method used to measure the diameter of the exit pupil of binoculars.

(iii) The diameter of the exit pupil of binoculars designed for night use is different from the diameter of the exit pupil of binoculars designed for use in daylight. State which exit pupil is the larger and explain why. **9**

(*c*) A pair of binoculars is marked "6 × 40".

(i) What does each of these numbers represent?

(ii) Calculate the diameter of the exit pupil of the binoculars. **4**

(*d*) To correct for certain lens defects, combinations of lenses are usually used in telescopes and binoculars instead of single simple lenses.

(i) Name one lens defect that can be corrected in this way.

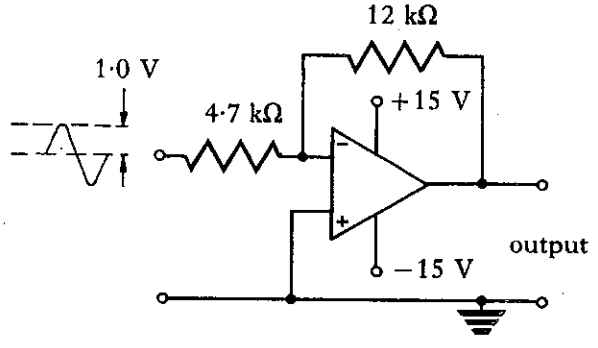
(ii) Explain how this defect affects the image seen when a simple lens is used. **3**

(20)

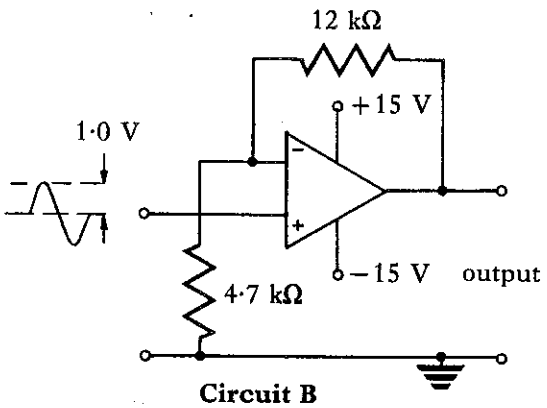
17. *ANALOGUE ELECTRONICS*

(*a*) An operational amplifier is used in two different circuits, A and B, as shown. In each case, the operational amplifier is connected to a power supply with outputs of +15 V and −15 V.

An a.c. signal of peak voltage 1·0 V is applied to the input of each circuit.



Circuit A



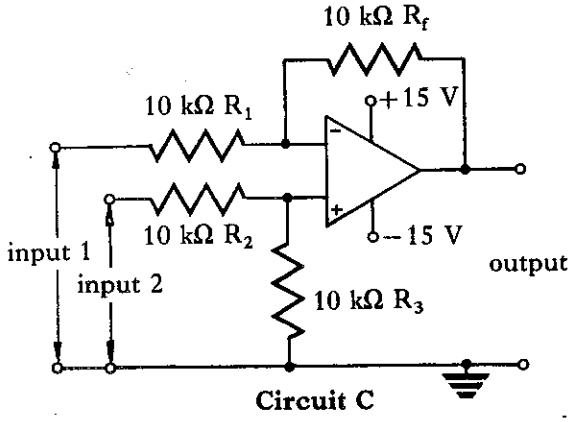
Circuit B

(i) In each circuit, how does the phase of the output compare with that of its input?

(ii) Calculate the peak output voltage of each circuit.

(iii) Sketch the waveform of the voltage obtained at the output of Circuit A if the input signal remains the same but the gain is changed to 20. Indicate the amplitude of this waveform. **9**

(*b*) An operational amplifier is used in the differential mode, as shown in Circuit C. *Marks*

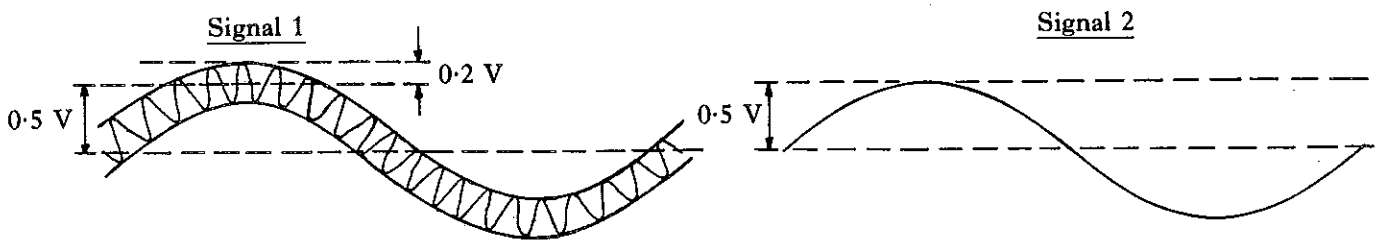


Circuit C

(i) What arithmetic operation does this circuit perform?

(ii) Calculate the output voltage of Circuit C if the voltage at input 1 is −0·7 V and the voltage at input 2 is +3·4 V. **4**

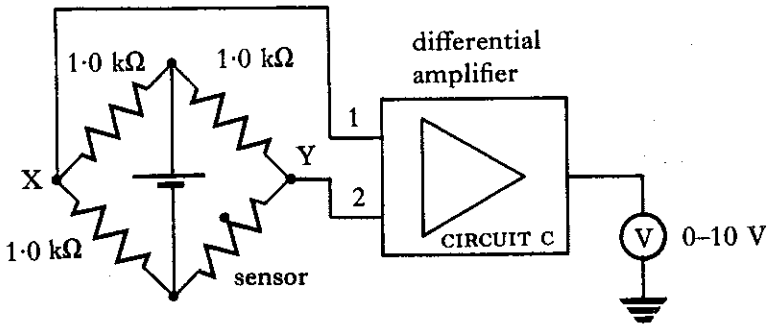
(*c*) The diagram shows the signals received at input 1 (Signal 1) and input 2 (Signal 2) of Circuit C when a microphone is connected to these inputs by means of a long pair of wires.



Signal 1 is a sine wave of frequency 1 kHz and amplitude 0·2 V combined with another sine wave of frequency 50 Hz and amplitude 0·5 V. Signal 2 is a sine wave of frequency 50 Hz and amplitude 0·5 V.

Sketch the waveform at the output of Circuit C. Indicate clearly its amplitude and frequency. **3**

(*d*) A temperature sensor has a resistance that varies between 1·0 kΩ at 0°C and 1·6 kΩ at 100°C. It is connected in the bridge circuit shown. The resistance of each of the three fixed resistors in the circuit is 1·0 kΩ.



The outputs X and Y of the bridge circuit are connected to inputs 1 and 2 respectively of Circuit C.

(i) What is the temperature of the sensor when the potential difference across XY is zero?

In order to change the gain of Circuit C, the values of R_f and R_3 are altered together, so that they remain equal. R_1 and R_2 are unchanged.

When the sensor is placed in boiling water, the potential difference across XY is 0·61 V.

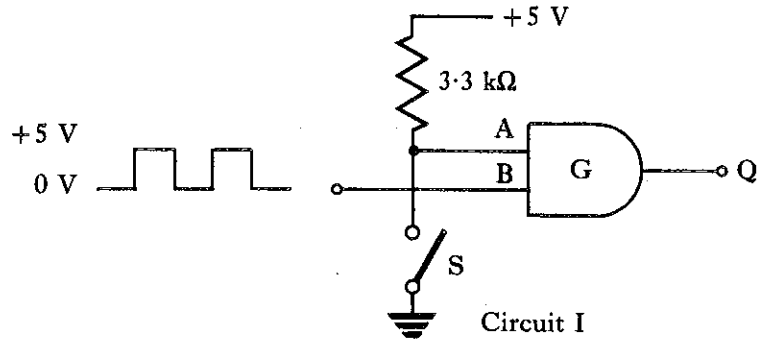
(ii) Calculate the values required for R_f and R_3 in Circuit C so that the voltmeter at the output of Circuit C will read 10·0 V. Assume that the values of R_1 and R_2 in Circuit C are unchanged at 10 kΩ. **4**

(20)

Marks

18. *DIGITAL ELECTRONICS*

(*a*) A logic gate G is connected as shown in Circuit I. Input A is connected to a resistor and switch, while a source of square waves is connected to input B of the gate.



Circuit I

(i) Identify the gate G.

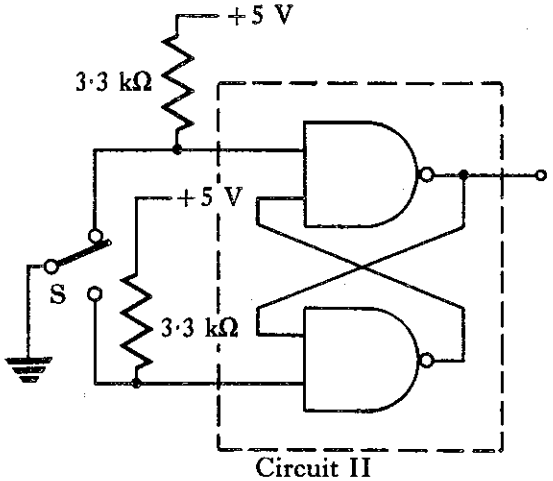
(ii) Construct a truth table for this gate.

(iii) State the logic level at input A with switch S open.

(iv) State the logic level at input A with switch S closed.

(v) Describe the output at Q for each of the two positions of switch S. **7**

(*b*) A simple on–off switch can give "contact bounce". Circuit II can be used to overcome this problem.



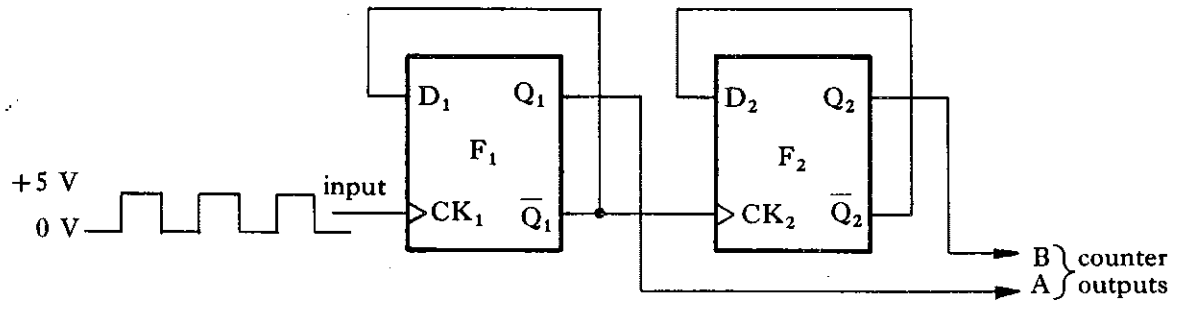
Circuit II

(i) Name the type of circuit within the dotted lines.

(ii) Identify the gates used to make up this circuit.

(iii) Why is a "debounced switch" normally needed at the input to a counter circuit? **4**

(*c*) Circuit III is a two-bit counter circuit constructed from two flip-flops (D-type). The flip-flops can change state only when there is a transition from logic "0" to logic "1" at the clock (CK) input.

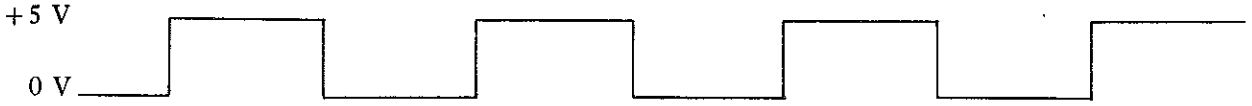


Circuit III

Marks

The waveform shown below represents the voltage at the CK_1 (clock) input of flip-flop F_1 over a short period of time.

At the beginning of this period of time, both outputs A and B of the counter are at logic "0".



Copy this waveform and draw the corresponding waveforms below it to show how the logic levels at the following points change with time:

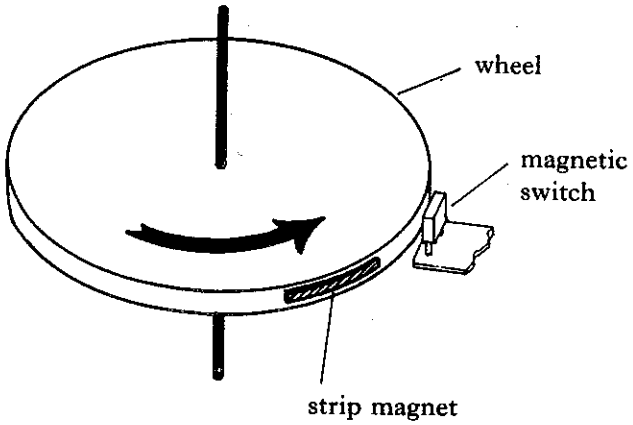
(i) output Q_1 of flip-flop F_1 (counter output A);

(ii) output $\overline{Q_1}$ of flip-flop F_1;

(iii) output Q_2 of flip-flop F_2 (counter output B).

[You should indicate clearly the times at which the outputs change in relation to the timing of the waveform shown.] **5**

(*d*) You are asked to construct an electronic circuit that will indicate the time in milliseconds taken by a strip magnet mounted on a wheel to go past a magnetic switch.



The magnetic switch has an output of logic "1" when it is close to a magnet and an output of logic "0" otherwise. It does not require a debounce circuit.

You are given the following apparatus:

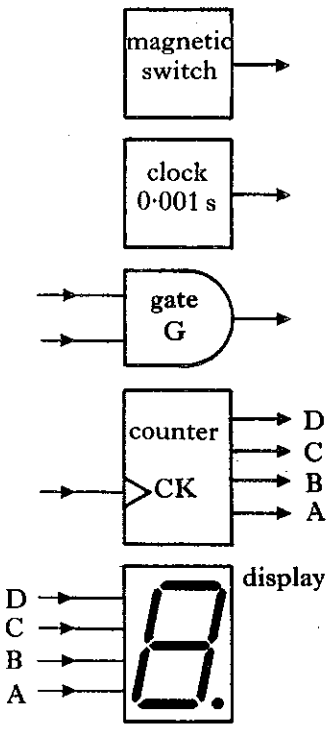
the magnetic switch;

a 1 kHz clock (source of square waves of period 0·001 s);

a gate of the same type as gate G in circuit I;

a four-bit counter;

a seven-segment display unit, capable of displaying the output of a four-bit counter as the numbers 0–9.



By means of a diagram, show the connections required to assemble this circuit. **4**

(20)

Marks

19. *NUCLEAR REACTORS*

(*a*) In a nuclear reactor, energy is released by a controlled chain reaction.

(i) State the value of the multiplication factor for such a controlled reaction.

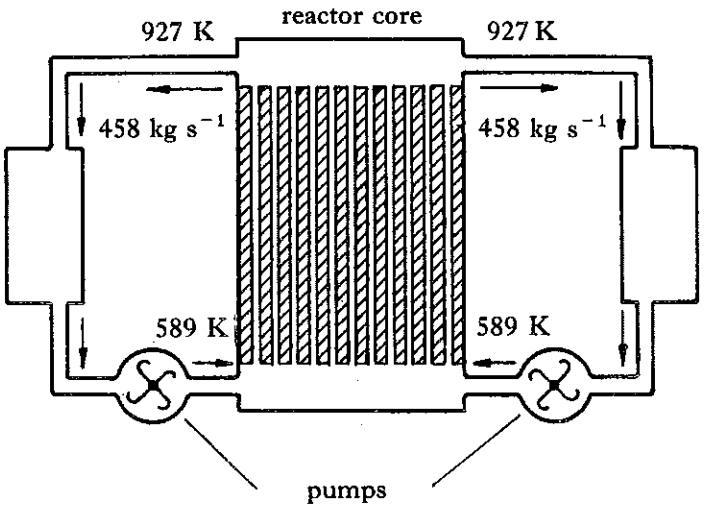
(ii) Explain what would happen to the reaction if the multiplication factor were to rise above this value. **4**

(*b*) (i) Explain the functions of the coolant in a reactor in a nuclear power station.

(ii) Give **one** important property of the coolant. **3**

(*c*) In the Hunterston "B" Advanced Gas-cooled Reactor (A.G.R.), there are eight pumps. Each is capable of circulating coolant gas at a rate of 458 kg s^{-1} through the whole of the reactor core.

The mean temperatures of the gas as it enters and leaves the core are 589 K and 927 K respectively.



(i) Calculate the power output of the reactor core when all eight pumps are operating, given that the specific heat capacity of the coolant gas is 1 070 J kg^{-1} K^{-1}.

(ii) Explain what would happen to the temperature of the reactor core if two of the pumps broke down and the power output of the core did not change.

(iii) In the event of such a breakdown, the temperature of the reactor core would be kept within safe limits by a control system. Explain clearly how this system operates. **9**

(*d*) Describe the stages by which electrical energy is obtained from nuclear energy in an A.G.R. **4**

(20)

[END OF QUESTION PAPER]