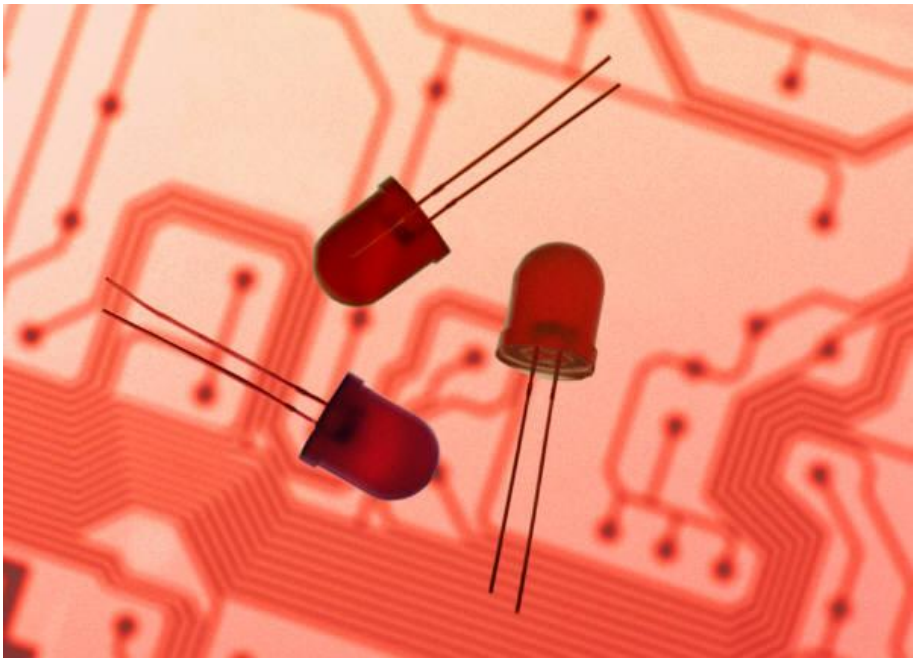
Wallace Hall Academy

CfE Higher Physics

Electricity



Exam Questions

Cover image: LEDs on a printed circuit board

Contents

DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	*Symbol*	*Value*	*Quantity*	*Symbol*	*Value*
Speed of light in vacuum	c	$3{\cdot}00 \times 10^{8}\ \mathrm{m\,s^{-1}}$	Planck's constant	h	$6{\cdot}63 \times 10^{-34}\ \mathrm{J\,s}$
Magnitude of the charge on an electron	e	$1{\cdot}60 \times 10^{-19}\ \mathrm{C}$	Mass of electron	m_e	$9{\cdot}11 \times 10^{-31}\ \mathrm{kg}$
Universal Constant of Gravitation	G	$6{\cdot}67 \times 10^{-11}\ \mathrm{m^3\,kg^{-1}\,s^{-2}}$	Mass of neutron	m_n	$1{\cdot}675 \times 10^{-27}\ \mathrm{kg}$
Gravitational acceleration on Earth	g	$9{\cdot}8\ \mathrm{m\,s^{-2}}$	Mass of proton	m_p	$1{\cdot}673 \times 10^{-27}\ \mathrm{kg}$
Hubble's constant	H_0	$2{\cdot}3 \times 10^{-18}\ \mathrm{s^{-1}}$			

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	Water	1·33
Crown glass	1·50	Air	1·00

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 }	Infrared
Helium-neon	633	Red

PROPERTIES OF SELECTED MATERIALS

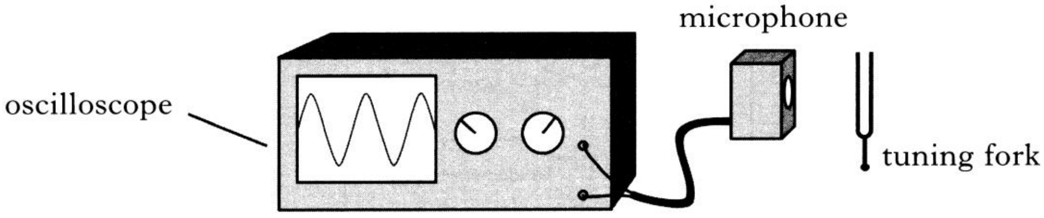
Substance	*Density*/kg m^{-3}	*Melting Point*/K	*Boiling Point*/K
Aluminium	$2{\cdot}70 \times 10^{3}$	933	2623
Copper	$8{\cdot}96 \times 10^{3}$	1357	2853
Ice	$9{\cdot}20 \times 10^{2}$	273	....
Sea Water	$1{\cdot}02 \times 10^{3}$	264	377
Water	$1{\cdot}00 \times 10^{3}$	273	373
Air	1·29	....	....
Hydrogen	$9{\cdot}0 \times 10^{-2}$	14	20

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

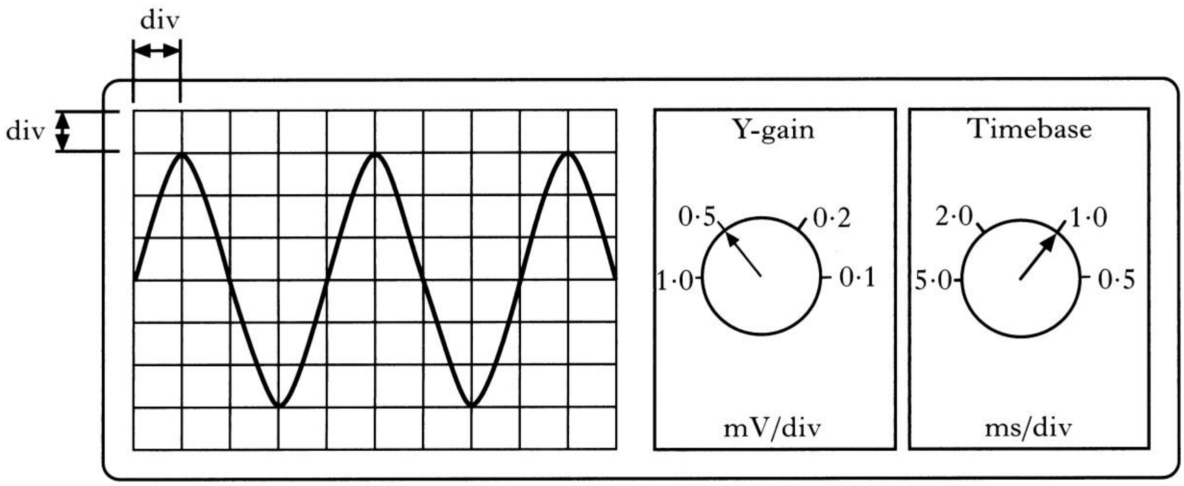
Electrons and energy

Measuring and monitoring alternating current

1. A microphone is connected to the input terminals of an oscilloscope. A tuning fork is made to vibrate and held close to the microphone as shown.



The following diagram shows the trace obtained and the settings on the oscilloscope.



Calculate:

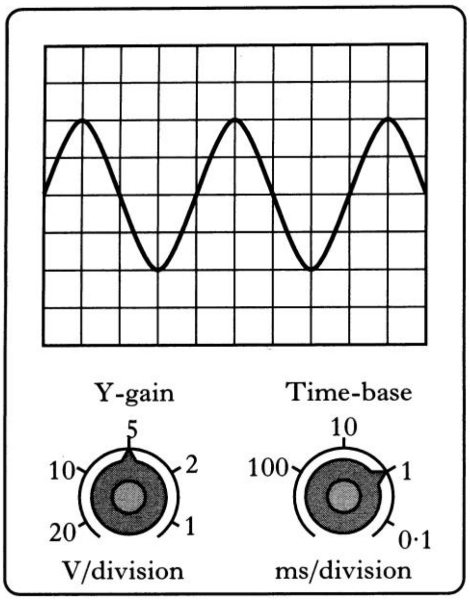
(a) the peak voltage of the signal; 1

(b) the r.m.s. voltage of the signal; 2

(c) the frequency of the signal. 2

(5)

2. The output from a signal generator is connected to the input terminals of an oscilloscope. The trace observed on the oscilloscope screen, the Y-gain setting and the time-base setting are shown on the diagram.



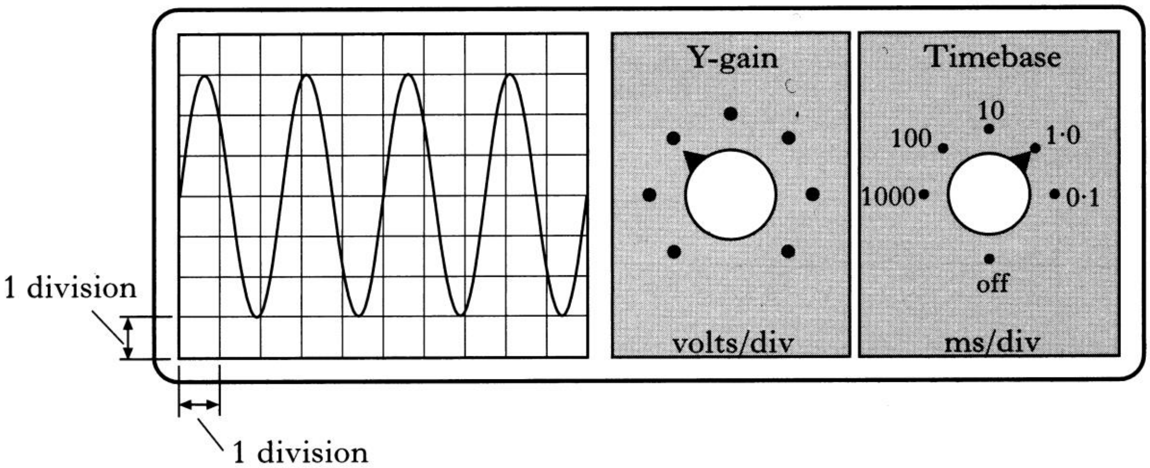
Calculate:

(a) the frequency of the signal;. 2

(b) the peak voltage of the signal. 1

(3)

3. A signal generator is connected to an oscilloscope. The output of the signal generator is set to a peak voltage of 15 V.
The following diagram shows the trace obtained, the Y-gain and the time-base controls of the oscilloscope. The scale for the Y-gain has been omitted.



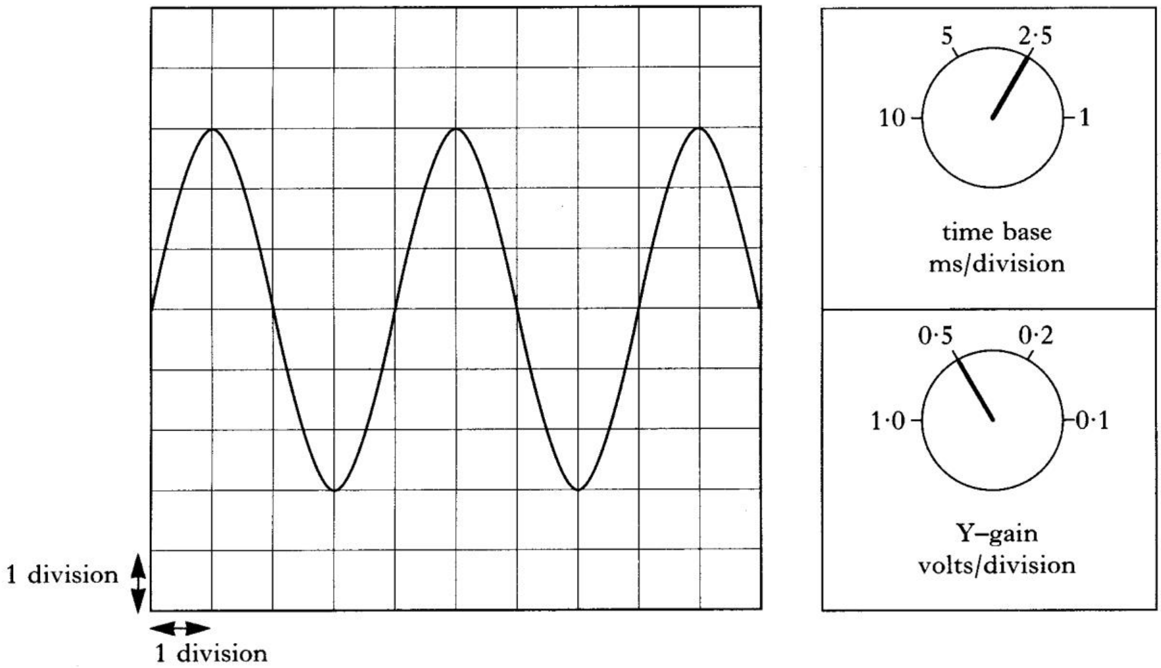
Calculate:

(a) the Y-gain setting of the oscilloscope;. 1

(b) the frequency of the signal. 2

(3)

4. The output from a signal generator is connected to the input terminals of an oscilloscope. A trace is obtained on the oscilloscope screen. The oscilloscope control settings and the trace on the oscilloscope screen are shown in the diagram below.



(a) Calculate the frequency of the output from the signal generator. 2

(b) The frequency and amplitude of the output from the signal generator are kept constant. The time base control setting is changed to 5 ms/division. What is the effect on the trace shown on the oscilloscope? 1

(3)

5. The peak value of an a.c. voltage is 12 V.

Calculate:

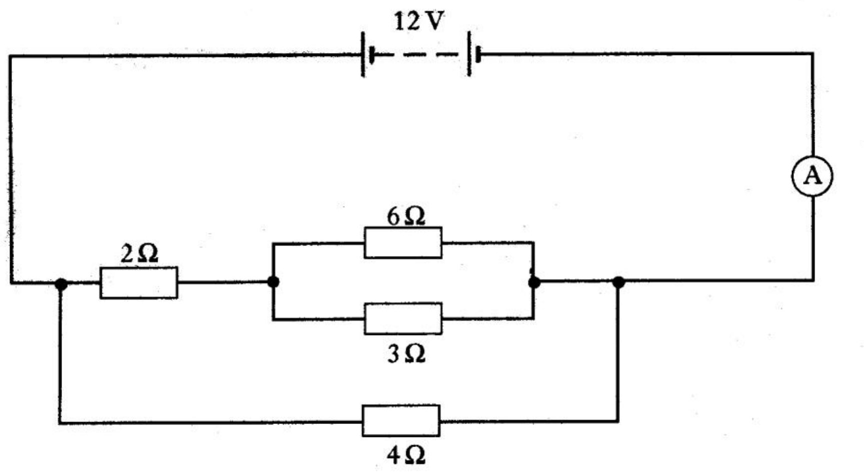
(a) the r.m.s. voltage; 2

(b) the power dissipated in a 4·0 Ω resistor by this voltage. 2

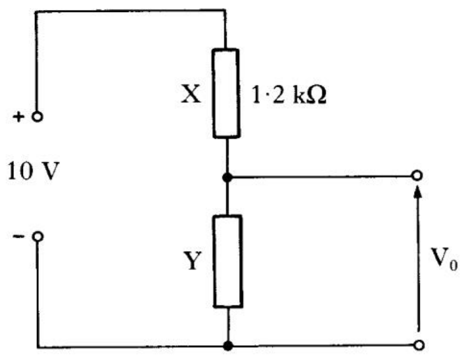
(4)

Current, voltage, power and resistance

1. Calculate the current in the ammeter in the circuit below. The battery has negligible internal resistance.

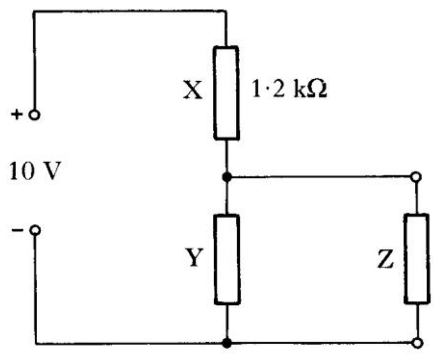


2. (a) A potential divider is used to provide an input voltage Vo from a 10 V supply as shown below. The supply has negligible internal resistance.



(i) The resistance of resistor X is 1·2 kΩ and the input voltage required is 6·0 V.
Calculate the resistance of resistor Y. 2

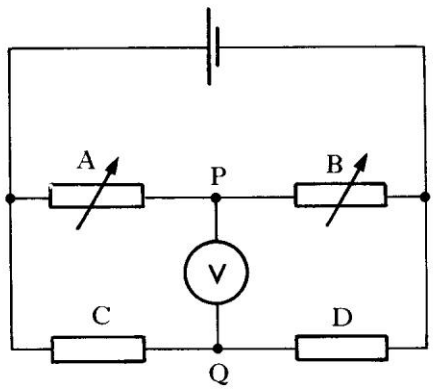
(ii) A load resistor Z is now connected across the output as shown below.



Explain why the voltage across Z is less than 6·0 V. 2

(iii) Calculate the voltage across Z when its resistance is 4·7 kΩ. 2

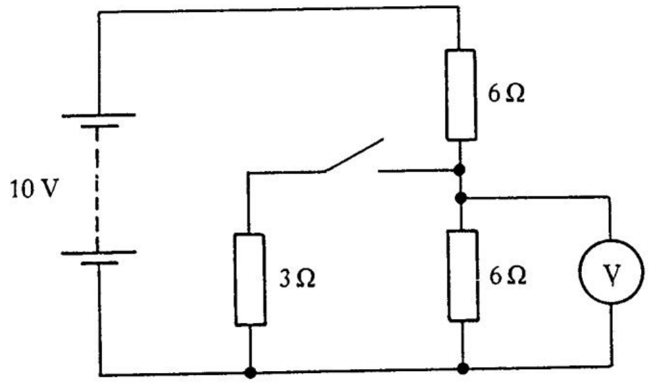
(b) Two potential dividers are connected in parallel to form the Wheatstone bridge circuit shown below.



The reading on the voltmeter is 0 V.
Describe how the resistances of A, B, C and D are related. 1

(7)

3. The circuit below shows resistors connected in a potential divider.



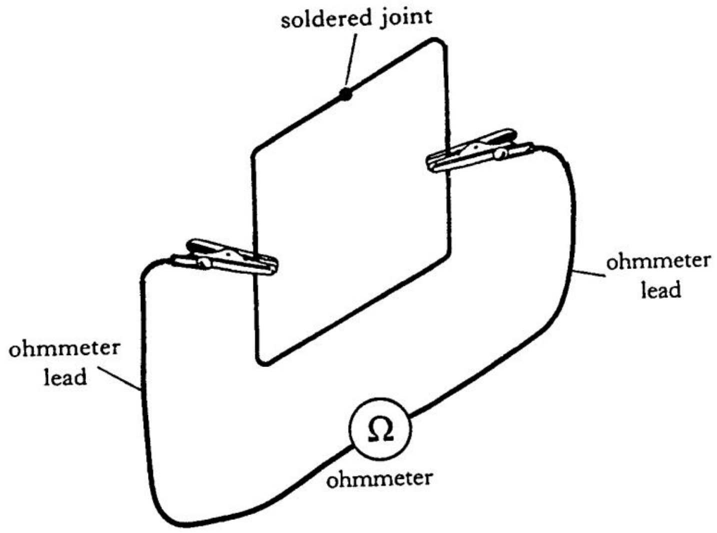
Calculate the reading on the voltmeter:

(a) when the switch is open; 2

(b) when the switch is closed. 2

(4)

4. The resistance of a length of bare uniform resistance wire is 30 Ω. The length of wire is folded into the shape of a square and the ends soldered together as shown below.



The resistance of the ohmmeter leads is negligible.

(a) Calculate the resistance displayed on the ohmmeter when it is connected as shown at the mid-points of opposite sides of the square. 2

(b) The right hand lead is now moved down to the bottom right-hand corner of the square.
State how the resistance displayed on the ohmmeter compares to that in part (a). You must justify your answer. 2

(4)

Electrical sources and internal resistance

1. (a) A supply of e.m.f. 10·0 V and internal resistance *r* is connected in a circuit as shown in Figure 1.

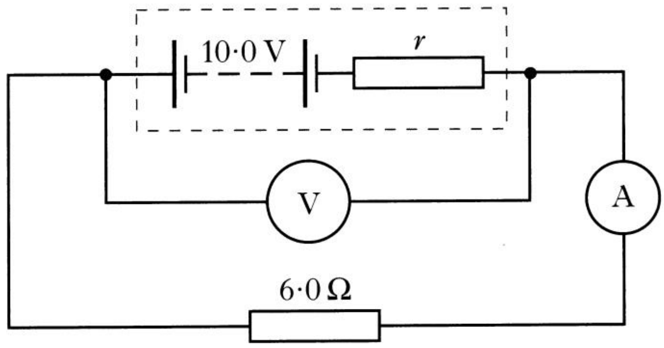


Figure 1

The meters display the following readings.

Reading on ammeter = 1·25 A
Reading on voltmeter = 7·50 V

(i) What is meant by an *e.m.f. of 10·0 V*? 1

(ii) Show that the internal resistance *r* of the supply is 2·0 Ω. 1

(b) A resistor R is connected to the circuit as shown in Figure 2.

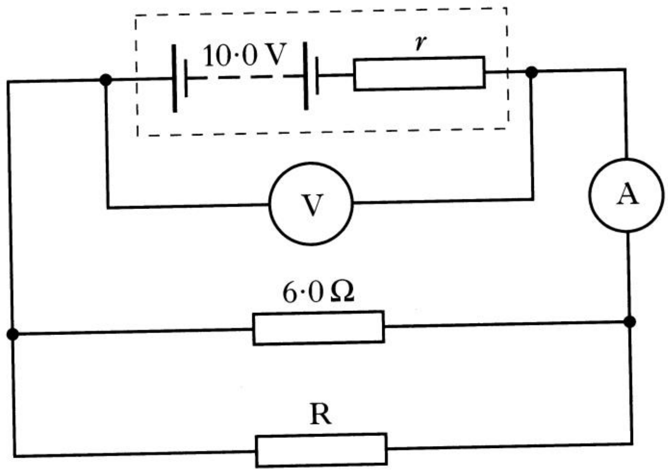


Figure 2

The meters now display the following readings.

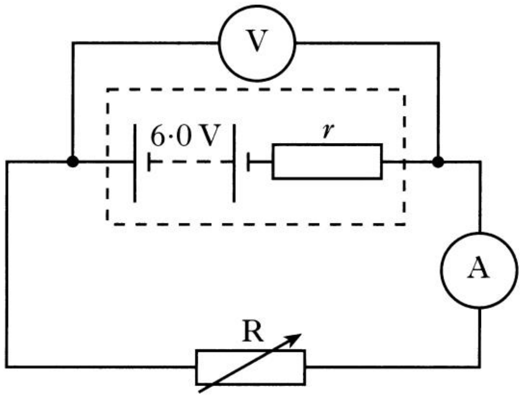
Reading on ammeter = 2·0 A
Reading on voltmeter = 6·0 V

(i) Explain why the reading on the voltmeter has decreased. 2

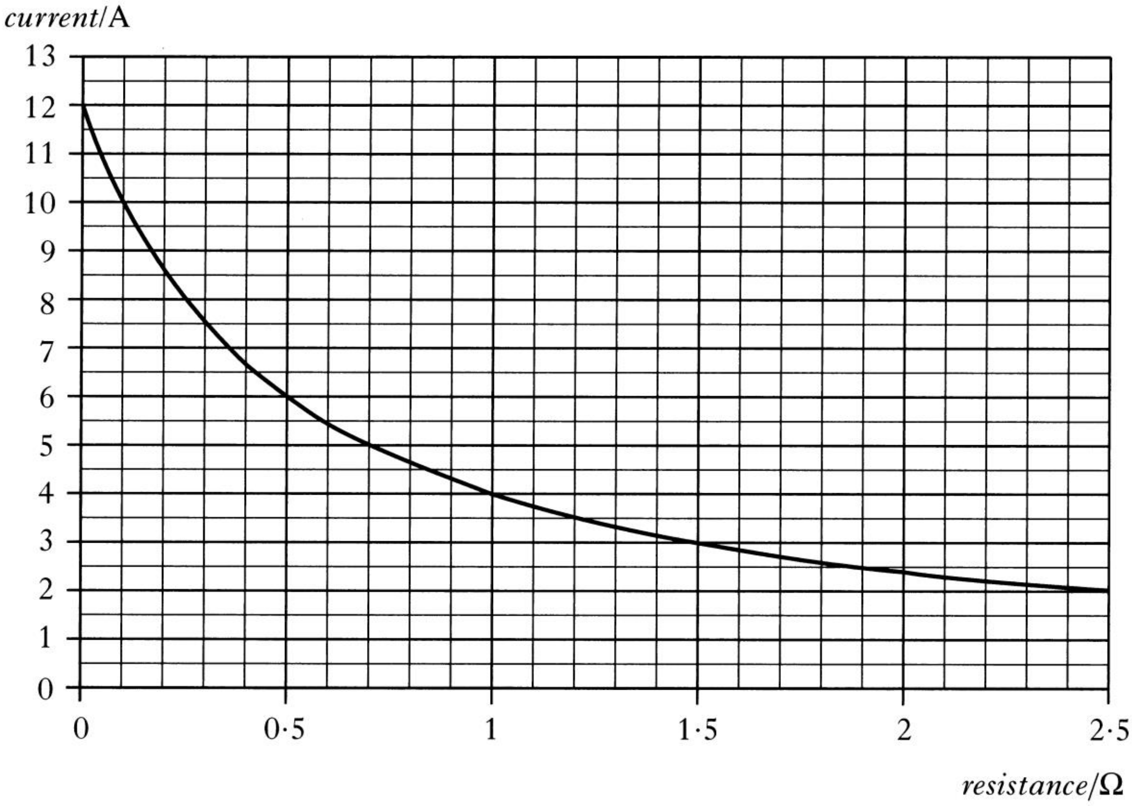
(ii) Calculate the resistance of resistor R. 3

(7)

2. A battery of e.m.f. 6·0 V and internal resistance *r* is connected to a variable resistor R as shown.



The graph shows how the current in the circuit changes as the resistance R increases.



(a) Use information from the graph to calculate:

(i) the lost volts in the circuit when the resistance of R is 1·5 Ω; 2

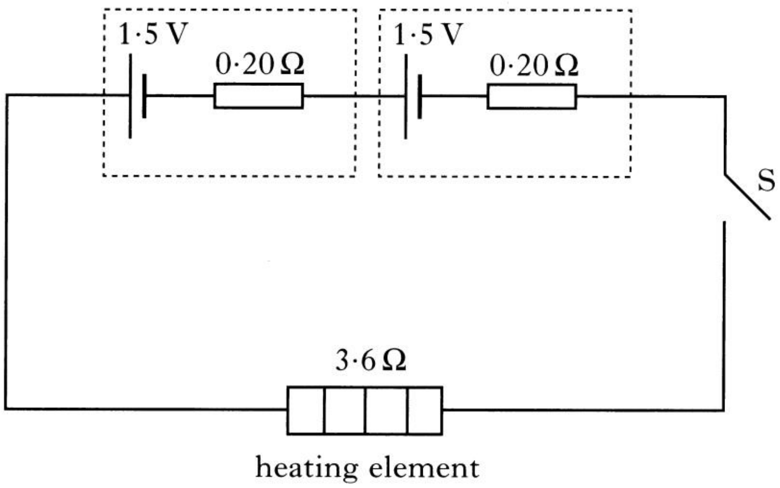
(ii) the internal resistance *r* of the battery. 2

(b) The resistance of R is now increased.
What effect, if any, does this have on the lost volts?
You must justify your answer. 2

(6)

3. Electrically heated gloves are used by skiers and climbers to provide extra warmth.

(a) Each glove has a heating element of resistance 3·6 Ω.
Two cells, each of e.m.f. 1·5 V and internal resistance 0·20 Ω, are used to operate the heating element.



Switch S is closed.

(i) Determine the value of the total circuit resistance. 1

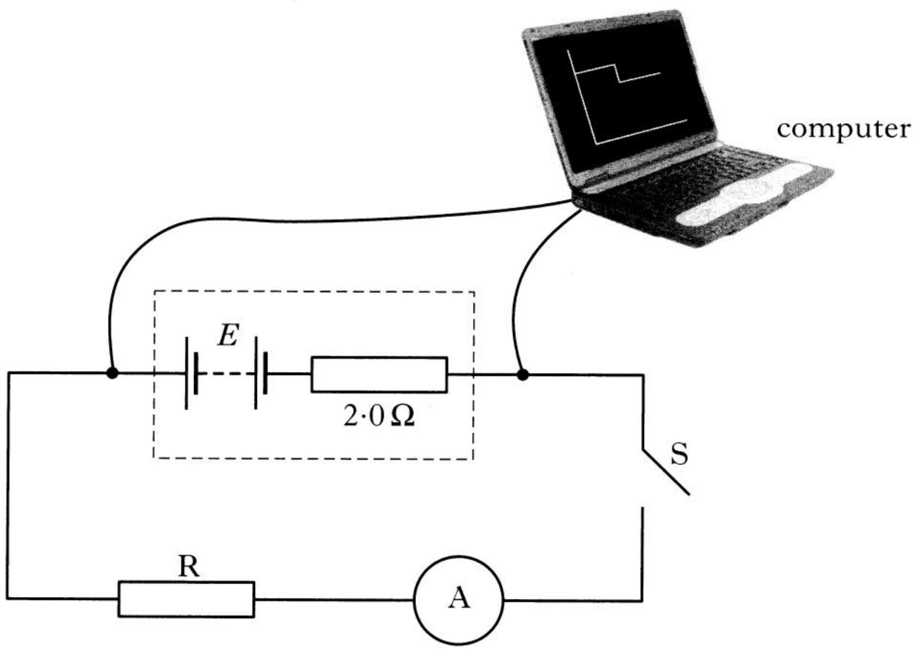
(ii) Calculate the current in the heating element. 2

(iii) Calculate the power output of the heating element. 2

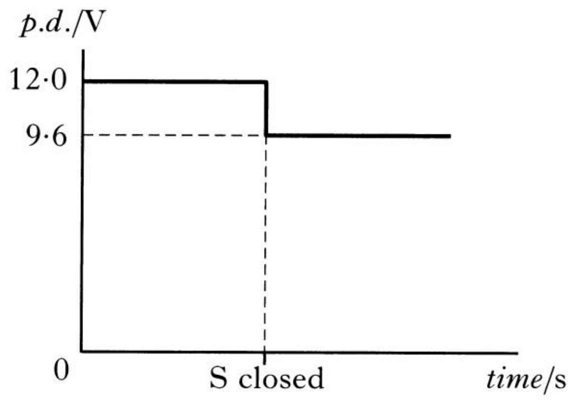
(b) When in use, the internal resistance of each cell gradually increases.
What effect, if any, does this have on the power output of the heating element?
Justify your answer. 2

(7)

4. A power supply of e.m.f. E and internal resistance $2{\cdot}0\ \Omega$ is connected as shown.



The computer connected to the apparatus displays a graph of potential difference against time.
The graph shows the potential difference across the terminals of the power supply for a short time before and after switch S is closed.



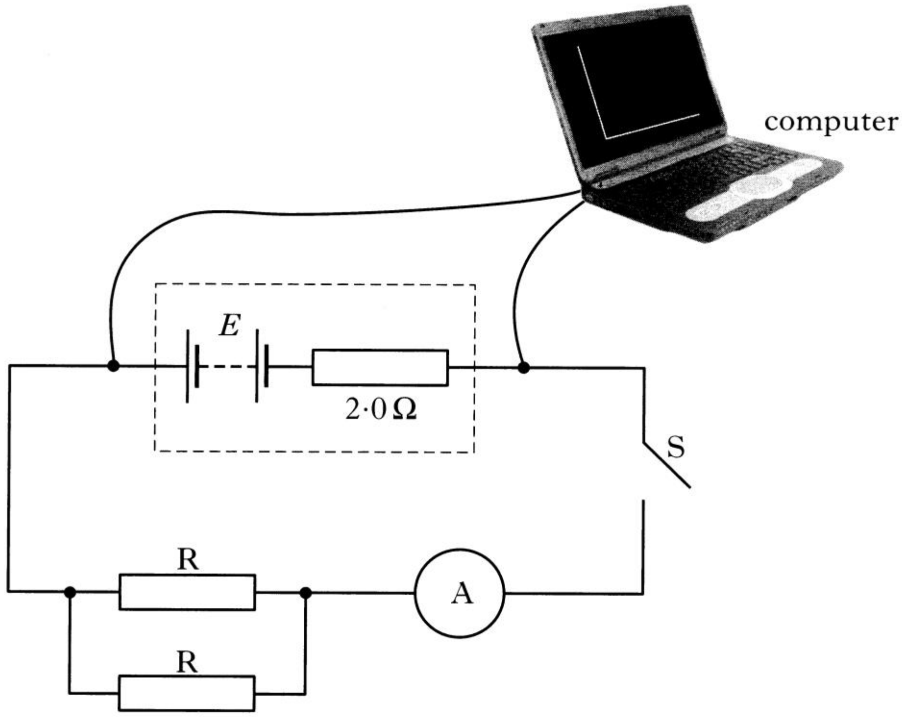
(a) State the e.m.f. of the power supply. 1

(b) Calculate:

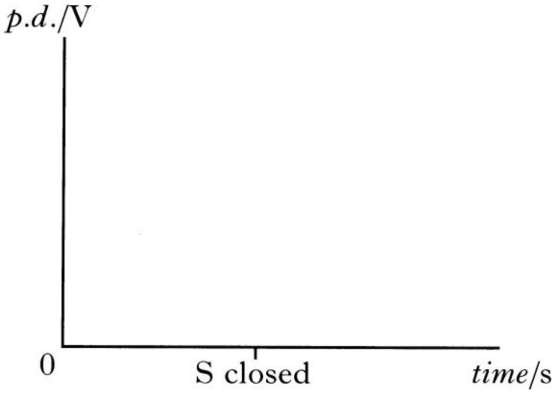
(i) the reading on the ammeter after switch S is closed; 2

(ii) the resistance of resistor R. 1

(c) Switch S is opened. A second identical resistor is now connected in parallel with R as shown.



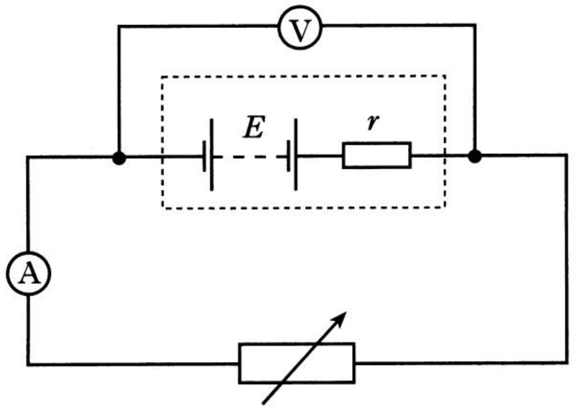
The computer is again connected in order to display a graph of potential difference against time.



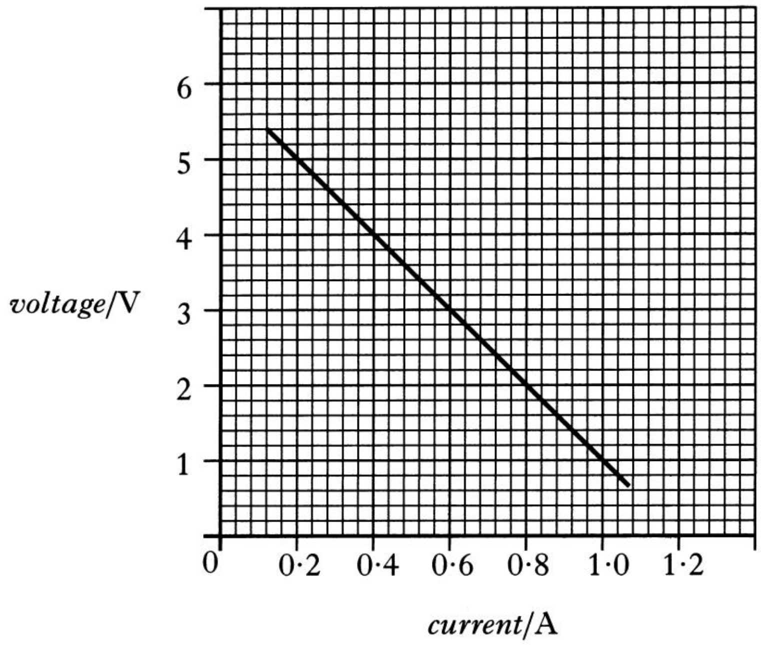
Copy and complete the new graph of potential difference against time showing the values of potential difference before and after switch S is closed. 2

(6)

5. A student sets up the following circuit to find the e.m.f. E and the internal resistance r of a battery.



Readings from the voltmeter and ammeter are used to plot the following graph.



(a) What is meant by the term *e.m.f.*? 1

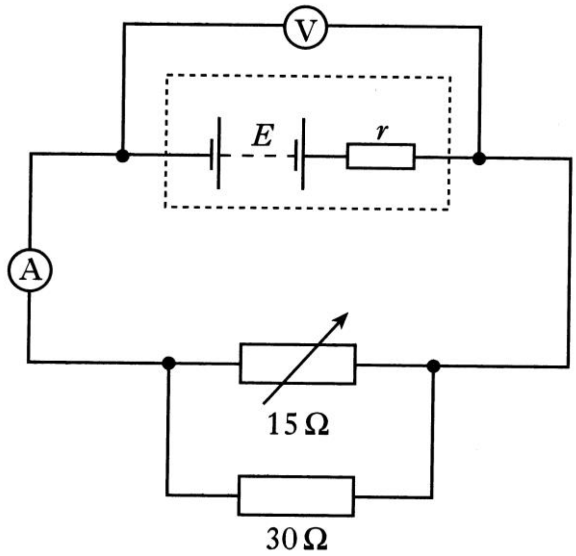
(b) (i) Use the graph to determine:

(A) the e.m.f.; 1

(B) the internal resistance of the battery. 2

(ii) Show that the variable resistor has a value of 15 Ω when the current is 0·30 A. 1

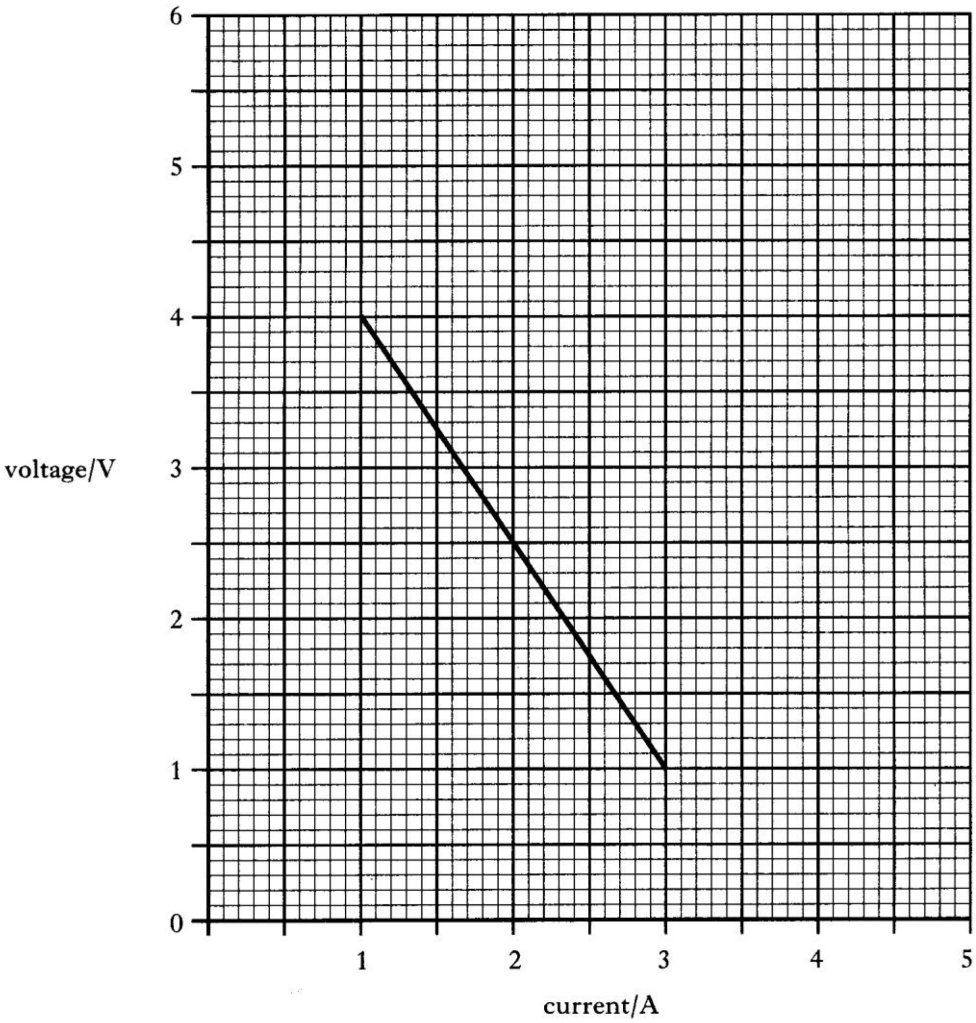
(c) Without adjusting the variable resistor, a 30 Ω resistor is connected in parallel with it.



Calculate the new reading on the ammeter. 2

(7)

6. The graph shows how the voltage across the terminals of a battery changes as the current from the battery is varied.

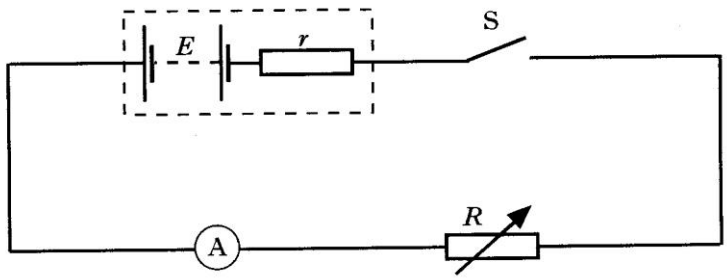


(a) Calculate the internal resistance of the battery. 2

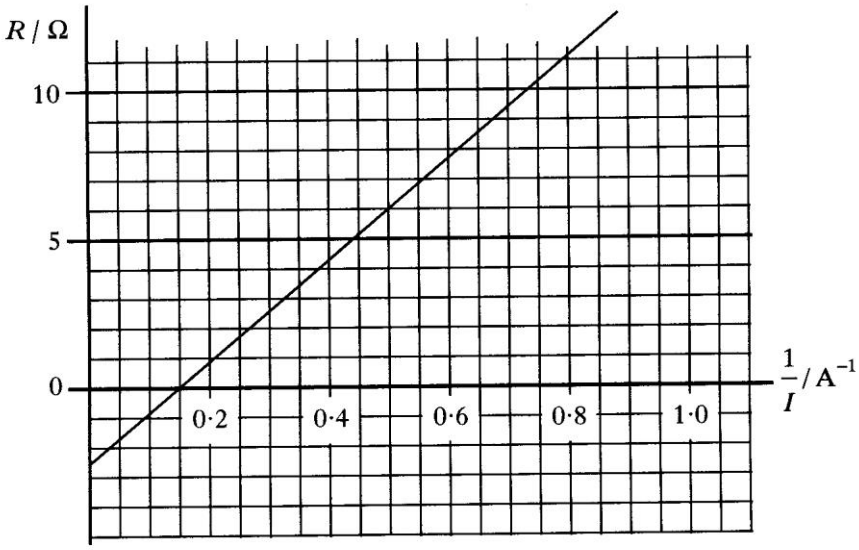
(b) State the current from the battery when it is short-circuited. 1

(3)

7. The circuit below is used to determine the internal resistance r of a battery of e.m.f. E.



The variable resistor provides known value of resistance R.
For each value of resistance R, the switch S is closed and the current I is noted.
For each current, the value of $1/I$ is calculated.
In one such experiment the following graph of R against $1/I$ is obtained.



(a) Conservation of energy applied to the complete circuit gives the following relationship.

$$E = I(R + r)$$

Show that this relationship can be written in the form

$$R = E/I - r.$$ 1

(b) Use the information from the graph to find:

(i) the internal resistance of the battery; 1

(ii) the e.m.f. of the battery. 2

(c) The battery is accidently short-circuited.
Calculate the current in the battery when this happens. 2

(6)

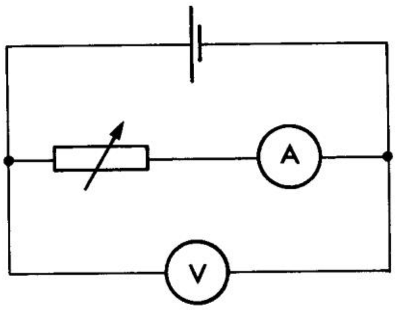
8. (a) A rechargeable cell is rated at 0·50 A h (ampere hour). This means that, for example, it can supply a constant current of 0·50 A for a period of 1 hour. The cell then requires to be recharged.

(i) What charge, in coulombs, is available from a fully charged cell? 1

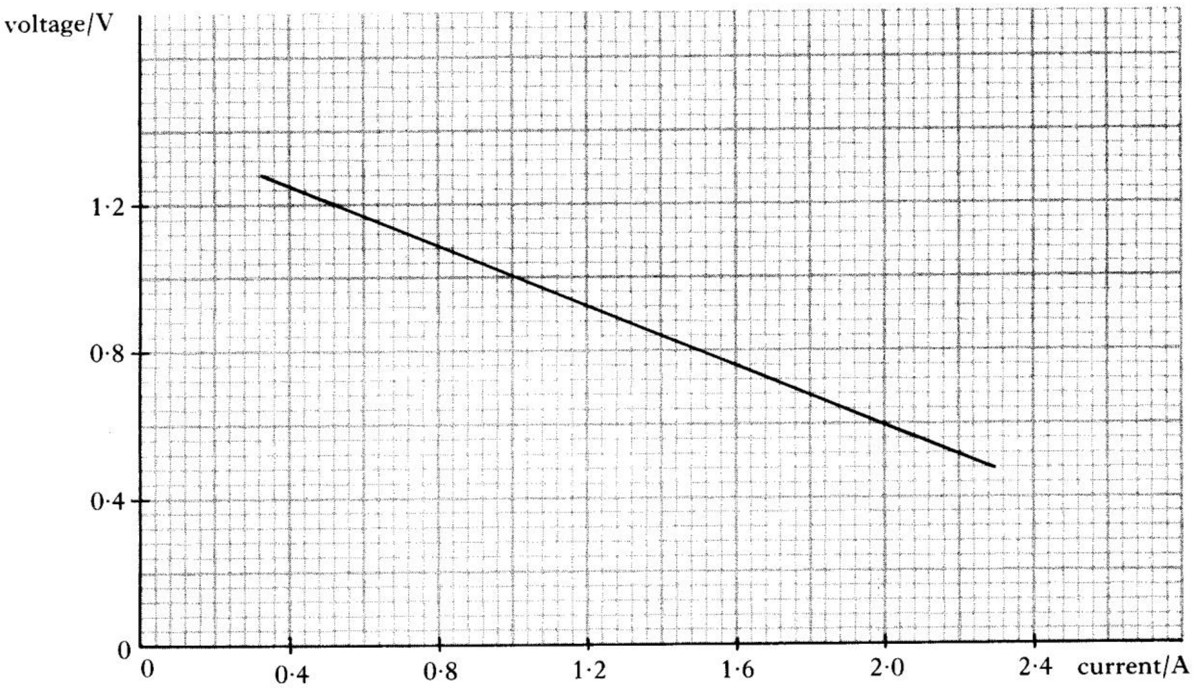
(ii) A fully charged cell is connected to a load resistor and left until the cell requires recharging. During this time, the p.d. across the terminals of the cell remains constant at 1·2 V.
Calculate the electrical energy supplied to the load resistor in this case. 2

(b) (i) State what is meant by the *e.m.f. of a cell*. 1

(ii) The circuit shown below is used in an experiment to find the e.m.f. and internal resistance of the rechargeable cell.



The voltmeter and ammeter readings for a range of settings of the variable resistor are used to produce the graph below.

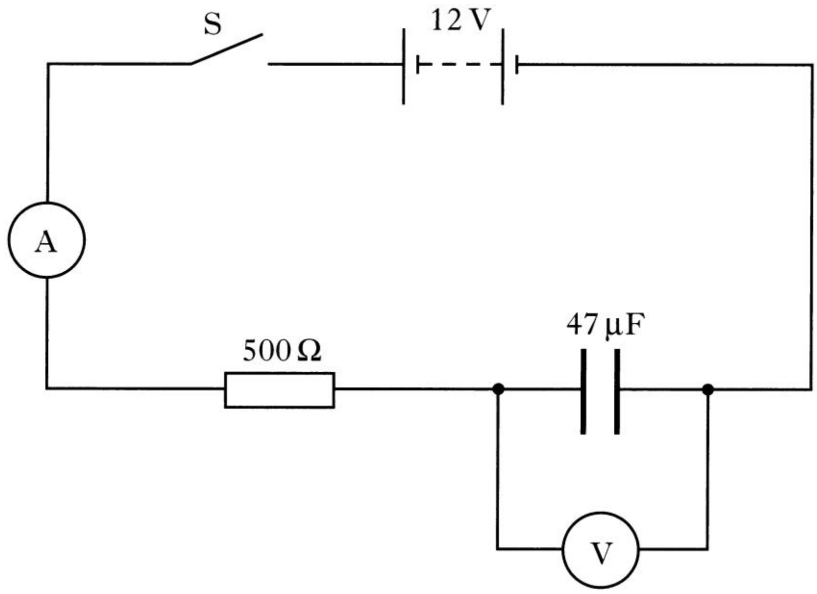


Use the graph to find the values for the e.m.f. **and** internal resistance of the cell. 3

(7)

Capacitors

1. A 12 volt battery of negligible internal resistance is connected in a circuit as shown.



The capacitor is initially uncharged. Switch S is then closed and the capacitor starts to charge.

(a) Sketch a graph of the current against time from the instant switch S is closed. Numerical values are not required. 1

(b) At one instant during the charging of the capacitor the reading on the ammeter is 5·0 mA.
Calculate the reading on the voltmeter at this instant. 3

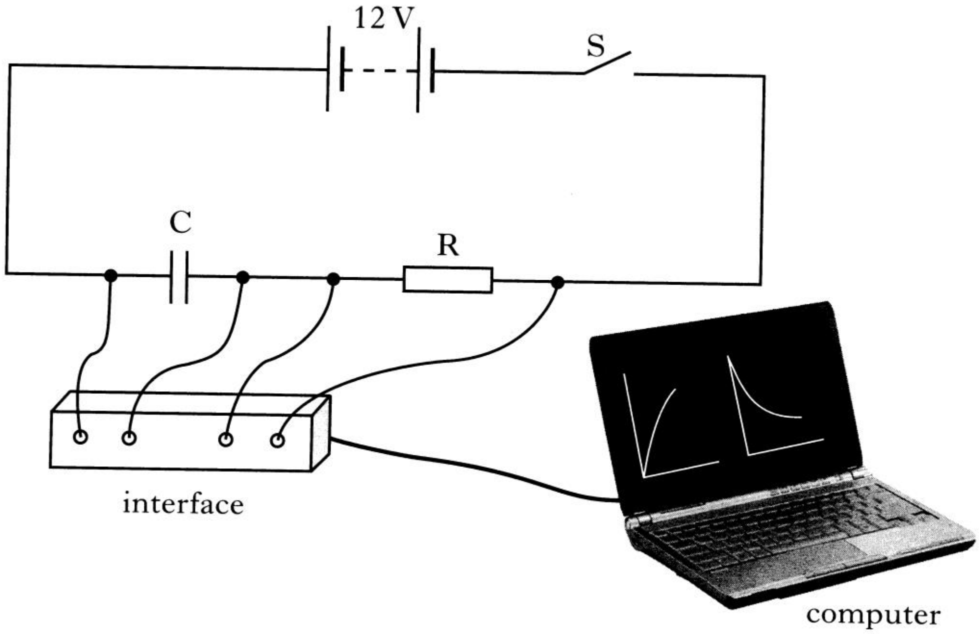
(c) Calculate the **maximum** energy stored in the capacitor in this circuit. 2

(d) The 500 Ω resistor is now replaced with a 2·0 kΩ resistor.
What effect, if any, does this have on the maximum energy stored in the capacitor?
Justify your answer. 2

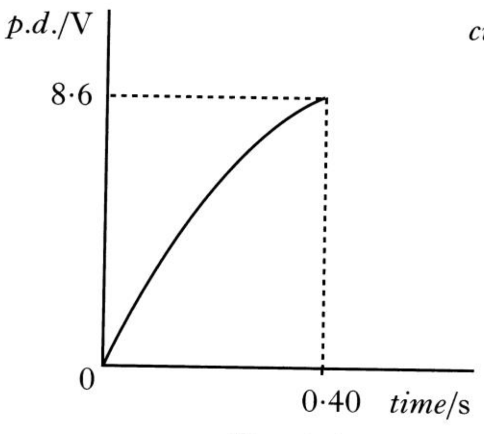
(8)

2. (a) State what is meant by the term *capacitance*. 1

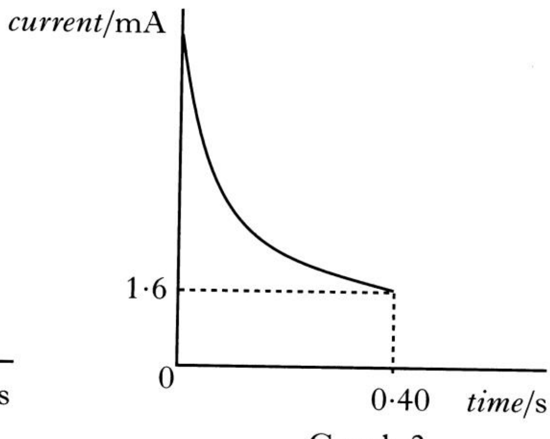
(b) An uncharged capacitor, C, is connected in a circuit as shown.



The 12 V battery has negligible internal resistance.
Switch S is closed and the capacitor begins to change.
The interface measures the current in the circuit and the potential difference (p.d.) across the capacitor. These measurements are displayed as graphs on the computer.
Graph 1 shows the p.d. across the capacitor for the first 0·40 s of charging.
Graph 2 shows the current in the circuit for the first 0·40 s of charging.



Graph 1



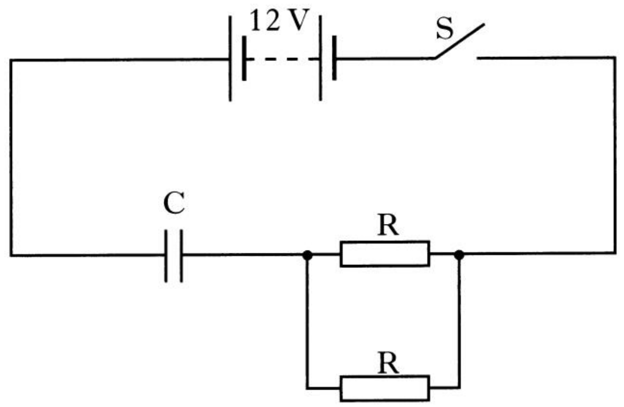
Graph 2

(i) Determine the p.d. **across resistor R** at 0·40 s. 1

(ii) Calculate the resistance R. 2

(iii) The capacitor takes 2·2 s to charge fully.
At that time it stores 10·8 mJ of energy.
Calculate the capacitance of the capacitor. 3

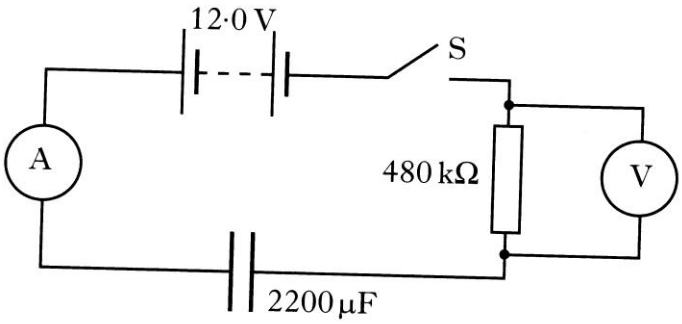
(c) The capacitor is now discharged.
A second, identical resistor is connected in the circuit as shown.



Switch S is closed.
Is the time taken for the capacitor to fully charge less than, equal to, or greater than the time taken to fully charge in part (b)?
Justify your answer. 2

(9)

3. An uncharged 2200 μF capacitor is connected in a circuit as shown.



The battery has negligible internal resistance.

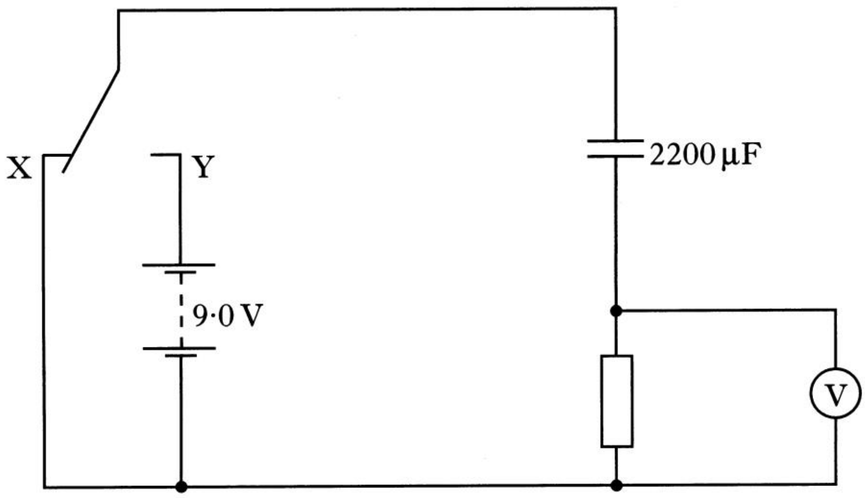
(a) Switch S is closed. Calculate the initial charging current. 2

(b) At one instant during the charging process the potential difference **across the resistor** is 3·8 V.
Calculate the charge stored in the capacitor at this instant. 3

(c) Calculate the **maximum** energy the capacitor stores in this circuit. 2

(7)

4. A student investigates the charging and discharging of a 2200 μF capacitor using the circuit shown.



The 9·0 V battery has negligible internal resistance.
Initially the capacitor is uncharged and the switch is at position X.
The switch is then moved to position Y and the capacitor charges fully in 1·5 s.

(a) (i) Sketch a graph of the p.d. across the **resistor** against time while the capacitor charges. Appropriate numerical values are required on both axes. 2

(ii) The resistor is replaced with one of higher resistance.
Explain how this affects the time taken to fully charge the capacitor. 1

(iii) At one instant during the charging of the capacitor the reading on the voltmeter is 4·0 V.
Calculate the charge stored by the capacitor at this instant. 3

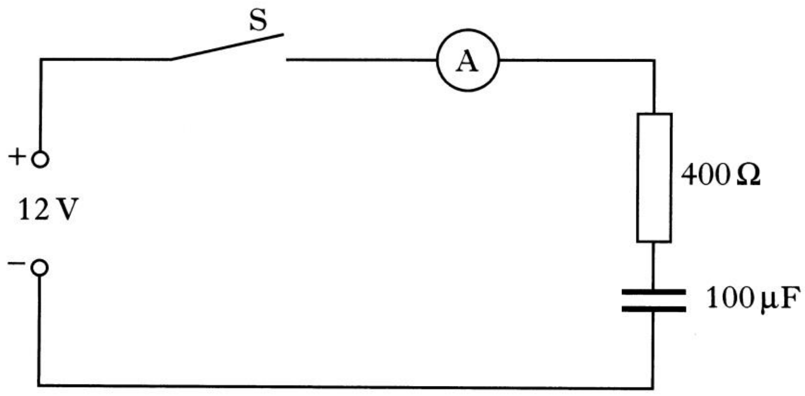
(b) Using the same circuit in a later investigation the resistor has a resistance of 100 kΩ. The switch is in **position Y** and the capacitor is fully charged.

(i) Calculate the maximum energy stored in the capacitor. 2

(ii) The switch is moved to position X. Calculate the maximum current in the resistor. 2

(10)

5. In an experiment, the circuit shown is used to investigate the charging of a capacitor.



The power supply has an e.m.f. of 12 V and negligible internal resistance. The capacitor is initially uncharged.
Switch S is closed and the current measured during charging. The graph of charging current against time is shown in figure 1.

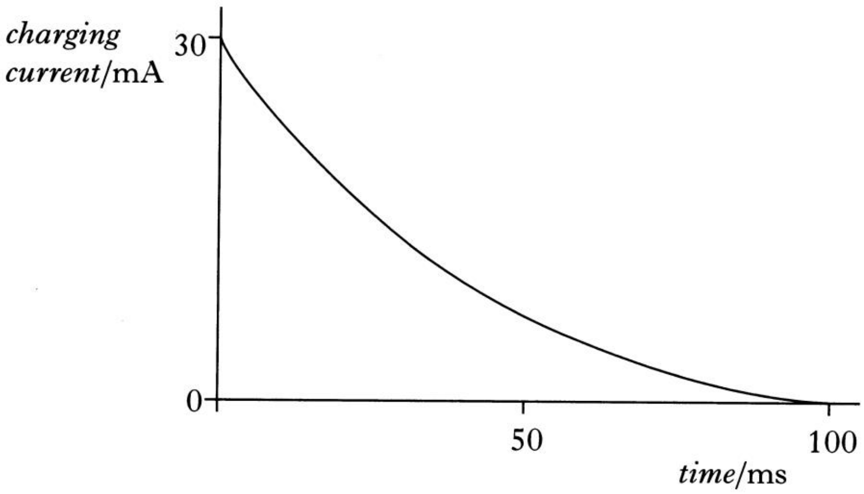


figure 1

(a) Sketch a graph of the voltage across the capacitor against time until the capacitor is fully charged. Numerical values are required on both axes. 2

(b) (i) Calculate the voltage across the capacitor when the charging current is 20 mA. 2

(ii) How much energy is stored in the capacitor when the charging current is 20 mA. 2

(c) The capacitor has a maximum working voltage 12 V.
Suggest **one** change to this circuit which would allow an initial charging current of greater than 30 mA. 1

(d) The 100 μF capacitor is now replaced with an uncharged capacitor of unknown capacitance and the experiment repeated. The graph of charging current against time for this capacitor is shown in figure 2.

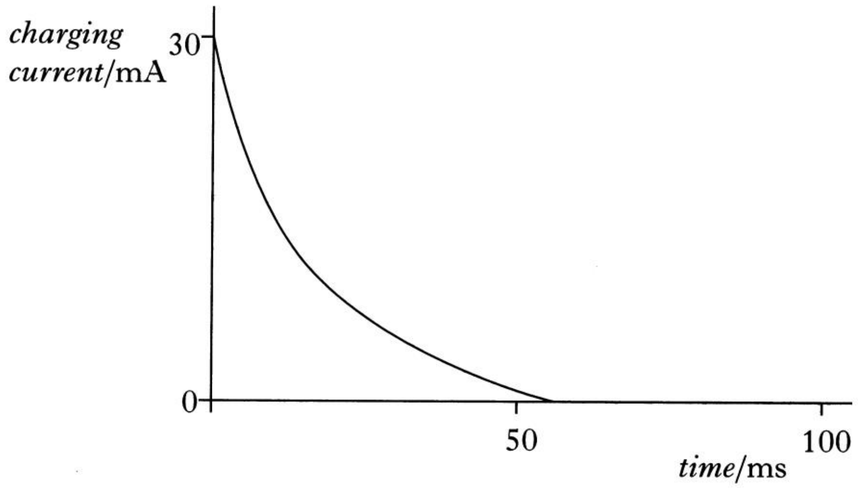
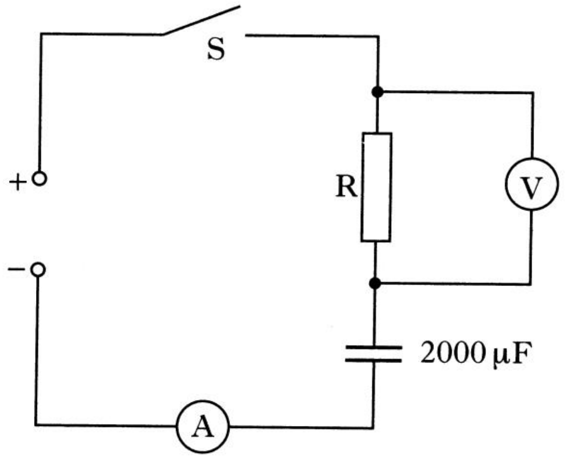


figure 2

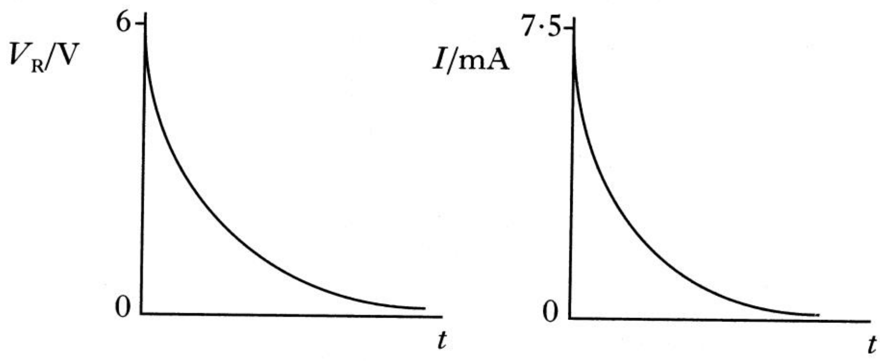
By comparing figure 2 with figure 1, determine whether the capacitance of this capacitor is greater than, equal to or less than 100 μF.
You must justify your answer. 2

(9)

6. (a) The circuit below is used to investigate the charging of a 2000 μF capacitor. The d.c. supply has negligible internal resistance.



The graph below shows how the potential difference V_R across the **resistor** and the current I in the circuit vary from time from the instant switch S is closed.

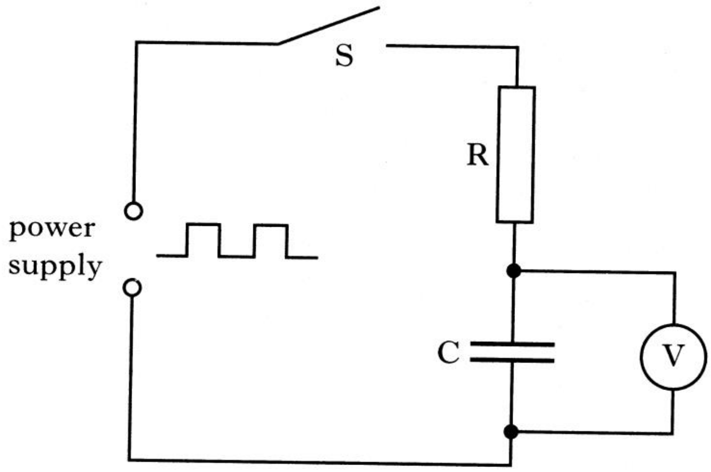


(i) What is the potential difference across the capacitor when it is fully charged? 1

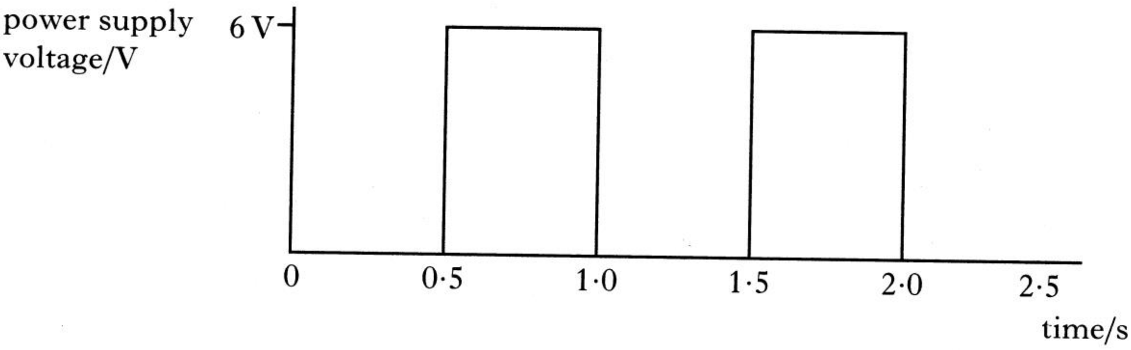
(ii) Calculate the energy stored in the capacitor when it is fully charged. 2

(iii) Calculate the resistance of R in the circuit above. 2

(b) The circuit below is used to investigate the charging and discharging of a capacitor.



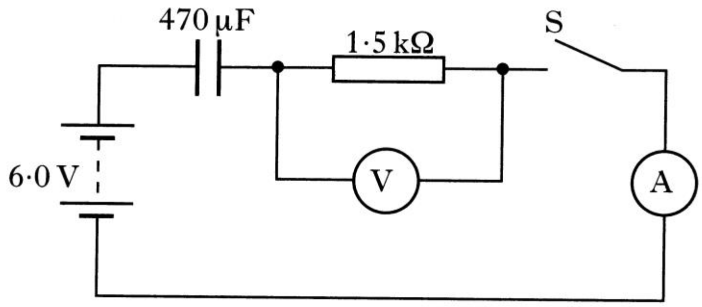
The graph below shows how the power supply voltage varies with time after switch S is closed.



The capacitor is initially uncharged.
The capacitor charges fully in 0·3 s and discharges fully in 0·3 s.
Sketch a graph of the reading on the voltmeter for the first 2·5 s after switch S is closed.
The axes on your graph must have the same numerical values as those in the above graph. 2

(7)

7. (a) The following diagram shows a circuit that is used to investigate the charging of a capacitor.



The capacitor is initially uncharged.
The capacitor has a capacitance of 470 μF and the resistor has a resistance of 1·5 kΩ.
The battery has an e.m.f. of 6·0 V and a negligible internal resistance.

(i) Switch S is now closed. What is the initial current in the circuit? 2

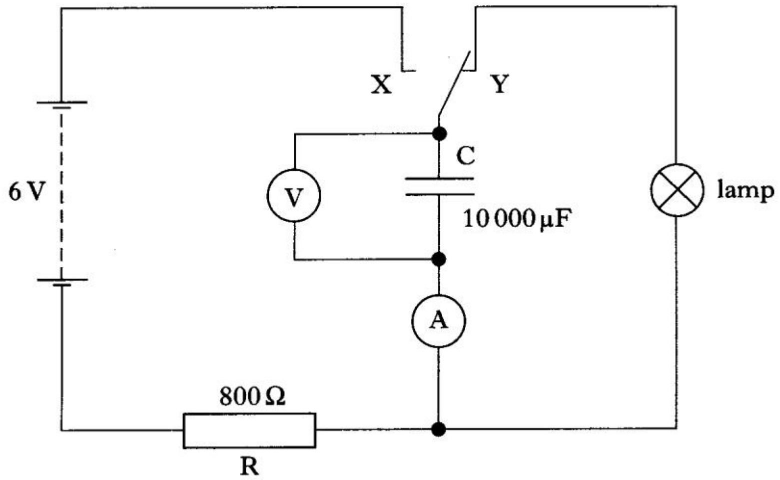
(ii) How much energy is stored in the capacitor when it is fully charged? 2

(iii) What change could be made to this circuit to ensure that the **same** capacitor stored **more** energy? 1

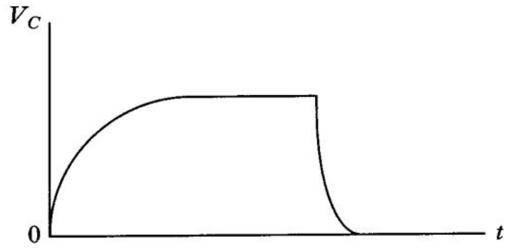
(b) A capacitor is used to provide the energy for an electronic flash in a camera. When the flash is fired, $6{\cdot}35 \times 10^{-3}$ J of the stored energy is emitted as light. The mean value of the frequency of photons of light from the flash is $5{\cdot}80 \times 10^{14}$ Hz.
Calculate the number of photons emitted in each flash of light. 3

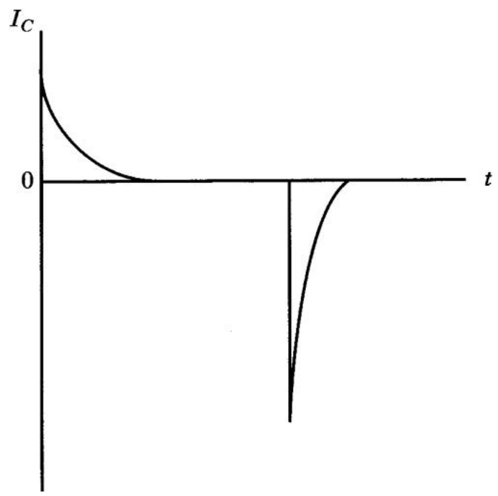
(8)

8. A student investigating the charging and discharging of a 10 000 μF capacitor using the circuit shown below. The 6 V supply has negligible internal resistance.



Initially the capacitor is uncharged and the switch is in position Y. The switch is moved to position X until the capacitor is fully charged and then finally back to position Y.
The graphs below show the p.d. V_C across the capacitor and the current I_C in the ammeter during the process.





(a) (i) State the p.d. across the capacitor when it is fully charged. 1

(ii) Calculate the maximum current during the charging process. 2

(iii) Sketch a graph showing how the p.d. across the resistor R varies with time during the charging process. Numerical values are not required. 1

(b) The student deduces from the graph of current against time for the discharge that the resistance of the lamp is less than 800 Ω.
Explain why the student's deduction is correct. 1

(c) Calculate the energy stored in the capacitor when it is fully charged. 2

(7)

9. 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.

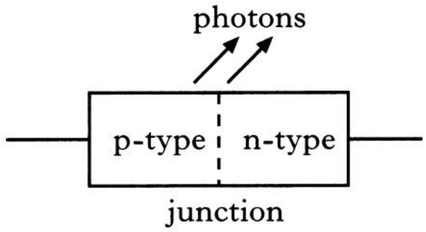
(a) Draw a diagram of your circuit. 2

(b) Sketch a graph showing the variation of current while the capacitor is charging. 1

(3)

Electrons at Work

1. An LED consists of a p-n junction as shown.



(a) Copy the diagram and add a battery so that the p-n junction is forward-biased. 1

(b) Using the terms *electrons*, *holes* and *photons*, explain how light is produced at the p-n junction of the LED. 1

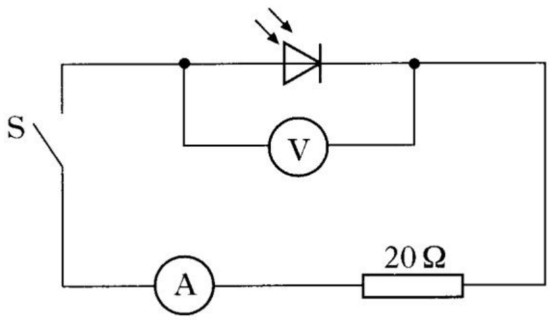
(c) The LED emits photons, of energy $3{\cdot}68 \times 10^{-19}$ J.

(i) Calculate the wavelength of a photon of light from this LED. 2

(ii) Calculate the minimum potential difference across the p-n junction when it emits photons. 2

(6)

2. A photodiode is connected in a circuit as shown below.



Switch S is open.
Light is shone on to the photodiode.
A reading is obtained on the voltmeter.

(a) (i) State the mode in which the photodiode is operating. 1

(ii) Describe the effect of light on the material of which the photodiode is made. 1

(iii) The irradiance of the light on the photodiode is increased. What happens to the reading on the voltmeter? 1

(b) Light of a constant irradiance is shone on the photodiode in the circuit shown above.
The following measurements are obtained with switch S open and then with switch S closed.

	S open	S closed
reading on voltmeter/V	0·508	0·040
reading on ammeter/mA	0·00	2·00

(i) What is the value of the e.m.f. produced by the photodiode for this light irradiance? 1

(ii) Calculate the internal resistance of the photodiode for this light irradiance. 2

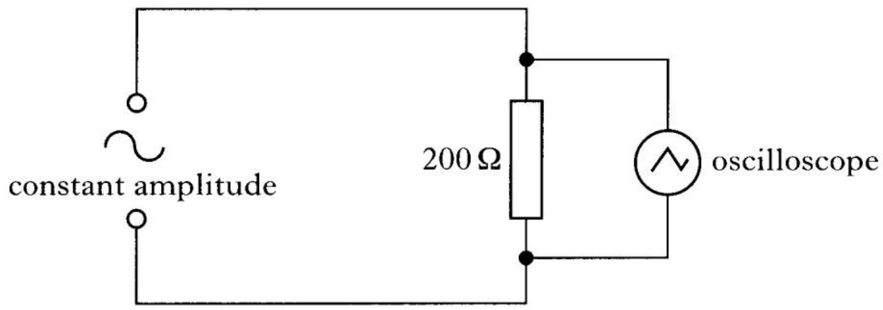
(c) In the circuit above, the 20 Ω resistor is now replaced with a 10 Ω resistor.
The irradiance of the light is unchanged.
The following measurements are obtained.

	S open	S closed
reading on voltmeter/V	0·508	0·021

Explain why the reading on the voltmeter, when S is closed, is smaller than the corresponding reading in part (b). 2

(8)

3. A circuit is set up as shown below.

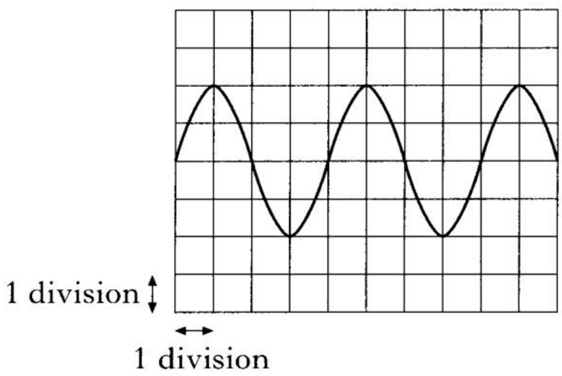


The amplitude of the output voltage of the a.c. supply is kept constant.

The settings of the controls on the oscilloscope are as follows:

y-gain setting = 5V/division
time-base setting = 2·5 ms/division

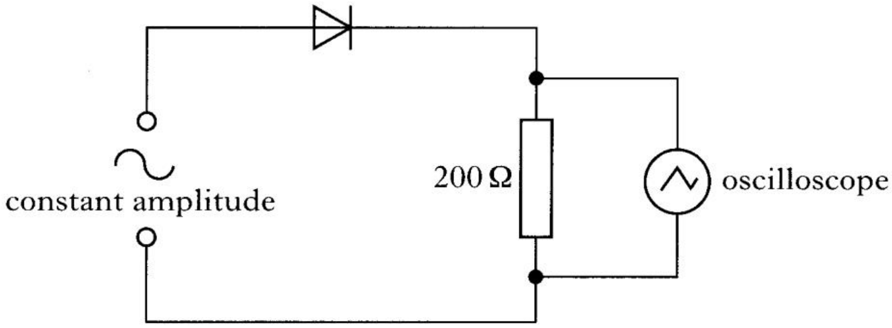
The following trace is displayed on the oscilloscope screen.



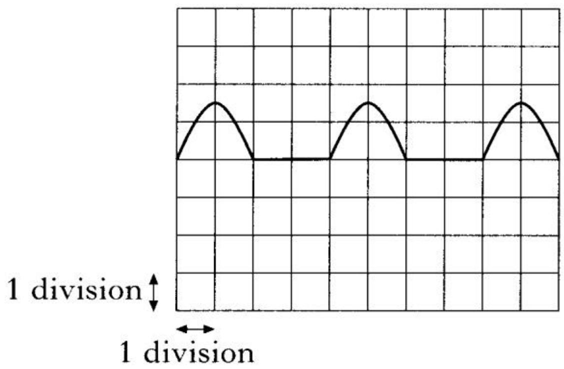
(a) (i) Calculate the frequency of the output from the a.c. supply. 2

(ii) Calculate the **r.m.s. current** in the 200 Ω resistor. 3

(b) A diode is now connected in the circuit as shown below.



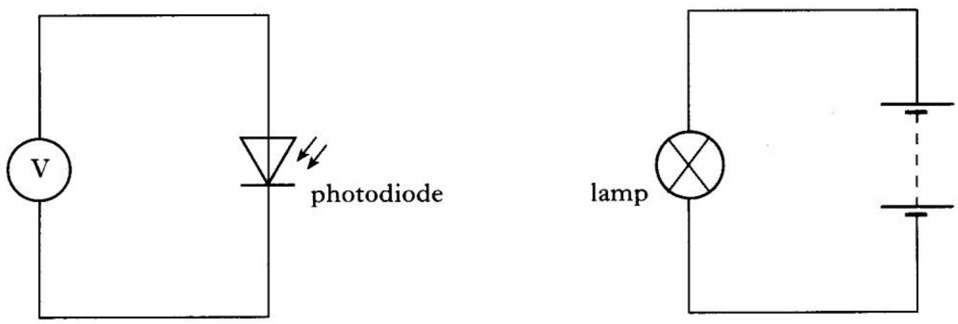
The setting on the controls of the oscilloscope remains unchanged. Connecting the diode to the circuit causes **changes** to the original trace displayed on the oscilloscope screen. The new trace is shown below.



Describe and explain the changes to the original trace. 2

(7)

4. The diagram shows a photodiode connected to a voltmeter. A lamp is used to shine light onto the photodiode.



The reading on the voltmeter is 0·5 V.
The lamp is now moved closer to the photodiode.
Using the terms **photons**, **electrons** and **holes**, explain why the voltmeter reading changes. 2

(2)

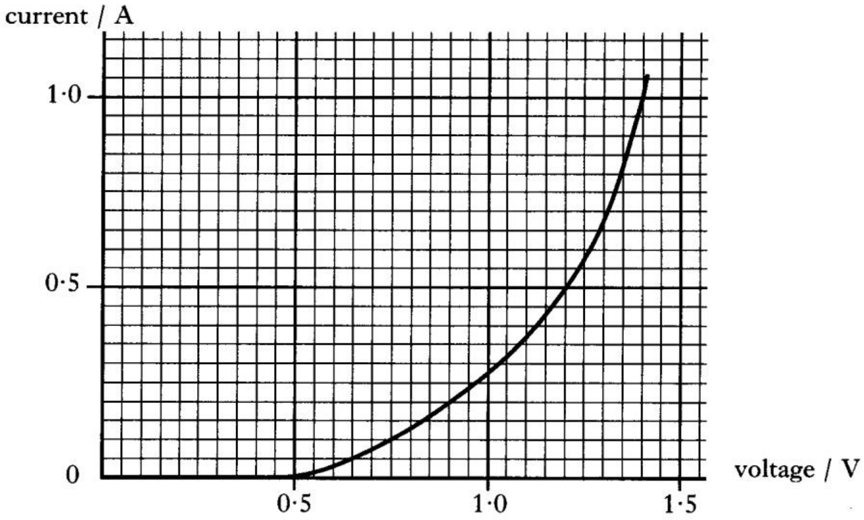
5. (a) The diagram below represents the p-n junction of a light emitting diode (LED).

(i) Draw a diagram showing the above p-n junction connected to a battery so that the junction is forward biased. 1

(ii) When the junction is forwarded biased, there is a current in the diode. Describe the movement of charge carriers which produces this current. 2

(iii) Describe how the charge carriers in the light emitting diode enable light to be produced. 2

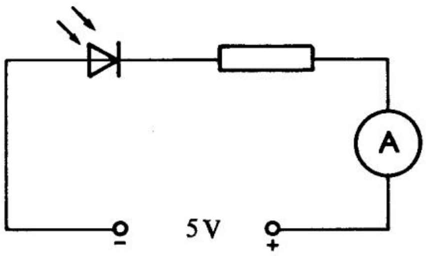
(b) The following graph shows the variation of current with voltage for a diode when it is forward biased.



(i) What is the minimum voltage required for the diode to conduct. 1

(ii) What happens to the resistance of the diode as the voltage is increased above this minimum value?
Use information from the graph to justify your answer. 2

6. The circuit below shows a photodiode connected in series with a resistor and an ammeter. The power supply has an output voltage 5 V and negligible internal resistance.



In a darkened room, there is no current in the circuit.
When light strikes the photodiode, there is a current in the circuit.

(a) Describe the effect of light on the material of which the photodiode is made. 1

(b) In which mode is the photodiode operating? 1

(c) When the photodiode is placed 1·0 m from a small lamp, the current in the circuit is 3·0 μA.
Calculate the current in the circuit when the photodiode is placed 0·75 m from the same lamp. 3

(5)

7. The power for a space probe is produced by an array of photodiodes. Each photodiode in the array acts as a photovoltaic cell. Under certain conditions the power output of the array is 150 W at 34 V.

(a) Calculate the current produced by the array. 2

(b) Explain how a photovoltaic cell can produce a small voltage. 2

(c) What happens to the irradiance of the solar radiation falling on the array if the probe moves to a position twice as far from the Sun? Justify your answer. 2

(6)

Uncertainties in Electricity

1. Measurements of the p.d. across a resistor and the current in the resistor give the following results.

   p.d. = (30·00 ± 0·03) V
   current = (2·00 ± 0·01) A

   Use these results to calculate the resistance of the resistor and express your answer in the form

   resistance ± uncertainty 3

Open-ended Questions

1. A battery is charged using a 12 V d.c. supply as shown in Diagram I.

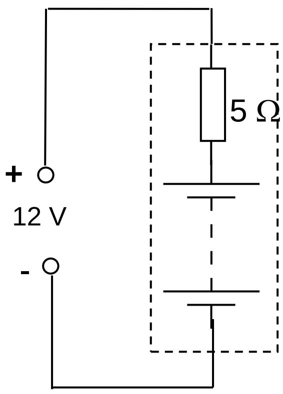


Diagram I

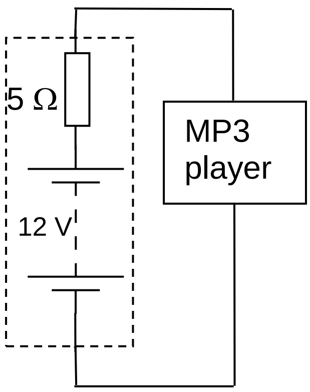


Diagram II

When charged it is connected to an MP3 player, as shown in Diagram II.

A teacher states that '*The energy used to charge the electrical battery is always greater than the energy that can be taken from it.'*

Use your knowledge of physics to comment on this statement.

You may use calculations to aid your comment.