TOPIC 2 Measurement Techniques

1 A student takes the following readings of the diameter of a wire: 1.52 mm, 1.48 mm, 1.49 mm, 1.51 mm, 1.49 mm. Which of the following would be the best way to express the diameter of the wire in the student's report?

A between 1.48 mm and 1.52 mm
B 1.5 mm
C 1.498 mm
D (1.498 ± 0.012) mm
E (1.50 ± 0.01) mm

N76/II/1

2 The formula for the period of a simple pendulum is $T = 2\pi\sqrt{(l/g)}$. Such a pendulum is used to determine g.

The fractional error in the measurement of the period T is $\pm x$ and that in the measurement of the length l is $\pm y$. The fractional error in the calculated value of g is no greater than

A $x + y$
B $x - y$
C $2x - y$
D $2x + y$
E xy

J77/II/3

3 In an experiment, the external diameter d_1 and internal diameter d_2 of a metal tube are found to be (64 ± 2) mm and (47 ± 1) mm respectively. The percentage error in $(d_1 - d_2)$ expected from these readings is at most

A 0.3% **B** 1% **C** 5% **D** 6% **E** 18%

J78/II/2; N81/II/5

4 Two species of ant have the same shape but all the linear dimensions of the giant ant are X times those of the normal ant. Assume that the weight each ant can lift depends only on the cross-sectional area of its muscles.

If the 'relative strength' of an ant is defined as the weight it can lift divided by its own weight, what is the value of the ratio

$$\frac{\text{relative strength of the giant ant}}{\text{relative strength of the normal ant}} ?$$

A $\frac{1}{X^3}$ **B** $\frac{1}{X}$ **C** 1 **D** X **E** X^2

N78/II/7

5 The density of a steel ball was determined by measuring its mass and diameter. The mass was measured within 1% and the diameter within 3%. The error in the calculated density of the steel ball is at most

A 2% **B** 4% **C** 8% **D** 10% **E** 28%

J79/II/8

6 The quantities p and q are measured with estimated errors δp and δq. The fractional uncertainty in p/q is at most

A $\delta p + \delta q$
B $\delta p - \delta q$
C $\delta p \cdot \delta q$
D $\frac{\delta p}{p} + \frac{\delta q}{q}$
E $\frac{\delta p}{p} - \frac{\delta q}{q}$

N79/II/2

7 A body, dropped from a tower, is timed to take (2.0 ± 0.1) s to fall to the ground. If the acceleration of free fall is taken as 10 m s^{-2}, the calculated height of the tower should be quoted as

A (20 ± 0.1) m
B (20 ± 0.2) m
C (20 ± 0.5) m
D (20 ± 1) m
E (20 ± 2) m

N80/II/5

8 The velocity of a liquid in a pipe can be calculated by measuring the force on a small disc placed in the centre of the pipe with its plane perpendicular to the flow. The equation relating the force to the velocity is

$$\text{force} = \text{constant} \times (\text{velocity})^2$$

If the velocity is to be found with a maximum uncertainty of 1%, what is the maximum permissible uncertainty in measuring the force?

A 0.25%
B 0.5%
C 1%
D 2%
E 4%

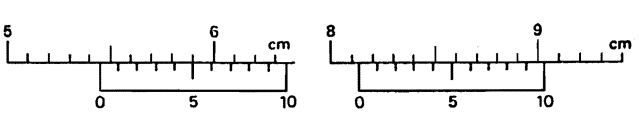
N82/II/1

9 A student makes measurements from which he calculates the speed of sound as 327.66 m s^{-1}. He estimates that his result is accurate only to ±3%. Which one of the following gives his result reduced to the appropriate number of significant figures?

A 300 m s^{-1}
B 327 m s^{-1}
C 327.7 m s^{-1}
D 328 m s^{-1}
E 330 m s^{-1}

J84/II/1

10 The diagrams show the scale readings of a travelling microscope focused in turn on each of the ends of a short metal rod.



On reading the vernier, an error of one division either way may be made.

What is the length of the rod and the associated error in the measurement?

A 2.66 ± 0.01 cm
B 2.68 ± 0.01 cm
C 2.68 ± 0.02 cm
D 2.70 ± 0.01 cm
E 2.70 ± 0.02 cm

J91/I/2

11 Which of the following experimental techniques reduces the systematic error of the quantity being investigated?

A timing a large number of oscillations to find a period
B measuring several internodal distances on a standing wave to find the mean internodal distance
C measuring the diameter of a wire repeatedly and calculating the average
D adjusting an ammeter to remove its zero error before measuring a current
E plotting a series of voltage and current readings for an ohmic device on a graph and using its gradient to find resistance

J92/I/1

12 A student uses vernier callipers to measure the sides of a rectangular wafer of silicon to the nearest tenth of a millimetre. The lengths are 10.4 mm, 6.3 mm and 2.3 mm.

Which of the following best expresses the volume of the wafer?

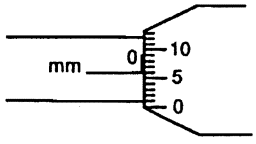
A 1.50696×10^2 mm^3
B 1.5070×10^2 mm^3
C 1.507×10^2 mm^3
D 1.51×10^2 mm^3
E 1.5×10^2 mm^3

N92/I/2

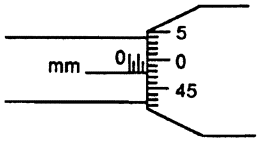
13 The diameter of a steel ball is measured using a micrometer screw gauge. A student takes an initial zero reading and then a reading of the diameter.

The diagrams show enlargements of the screw gauge readings.

zero reading



diameter reading

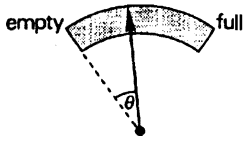


What is the diameter of the ball?

A 3.48mm
B 2.04mm
C 1.98mm
D 1.92mm
E 1.42mm

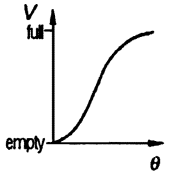
J93/I/1

14 A petrol gauge in a car indicates the volume V of fuel in the tank. V is given by the angular deflection θ of the pointer on a dial.

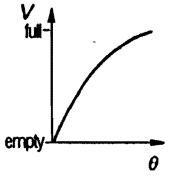


Below are the calibration curves for five different gauges.

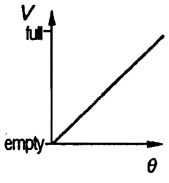
gauge A



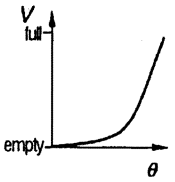
gauge B



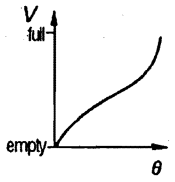
gauge C



gauge D



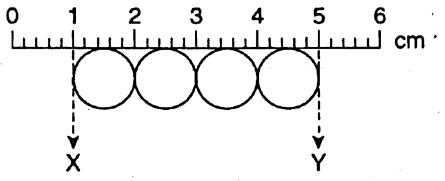
gauge E



For **low** fuel levels in the tank, which gauge would be most sensitive?

N93/I/30

15 A student attempts to measure the diameter of a steel ball by using a metre rule to measure four similar balls in a row.



The student estimates the positions on the scale to be as follows.

X (1.0 ± 0.2) cm
Y (5.0 ± 0.2) cm

What is the diameter of a steel ball together with its associated uncertainty?

A (1.0 ± 0.05) cm
B (1.0 ± 0.1) cm
C (1.0 ± 0.2) cm
D (1.0 ± 0.24) cm

J94/I/2; J99/I/2

16 In a simple electrical circuit, the current in a resistor is measured as (2.50 ± 0.05) mA. The resistor is marked as having a value of $4.7\ \Omega \pm 2\%$.

If these values were used to calculate the power dissipated in the resistor, what would be the percentage uncertainty in the value obtained?

A 2% **B** 4% **C** 6% **D** 8%

N94/I/2

17 When comparing systematic and random errors, the following pairs of properties of errors in an experimental measurement may be contrasted:

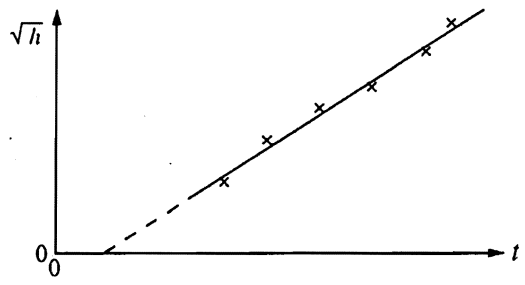
P_1 : error can possibly be eliminated
P_2 : error cannot possibly be eliminated
Q_1 : error is of constant sign and magnitude
Q_2 : error is of varying sign and magnitude
R_1 : error will be reduced by averaging repeated measurements
R_2 : error will not be reduced by averaging repeated measurements

Which properties apply to **random** errors?

A P_1, Q_1, R_2
B P_1, Q_2, R_2
C P_2, Q_2, R_1
D P_2, Q_1, R_1

J95/I/2

18 A student measures the time t for a ball to fall from rest through a vertical distance h. Knowing that the equation $h = \frac{1}{2}at^2$ applies, the student plots the graph shown.

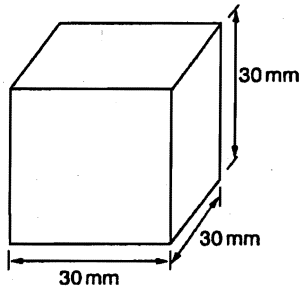


Which of the following is an explanation for the intercept?

A Air resistance has not been taken into account for larger values of h.
B There is a constant delay between starting the timer and releasing the ball.
C There is an error in the timer that consistently makes it run fast.
D The student should have plotted h against t^2.

N95/I/2; N99/I/2

19 The dimensions of a cube are measured with vernier callipers.



The measured length of each side is 30 mm. If the vernier callipers can be read with an uncertainty of ± 0.1 mm, what does this give for the approximate uncertainty in the value of its volume?

A $\frac{1}{27}$ % **B** $\frac{3}{10}$ % **C** $\frac{1}{3}$ % **D** 1%

J96/I/2

20 Four students each made a series of measurements of the acceleration of free fall g. The table shows the results obtained.

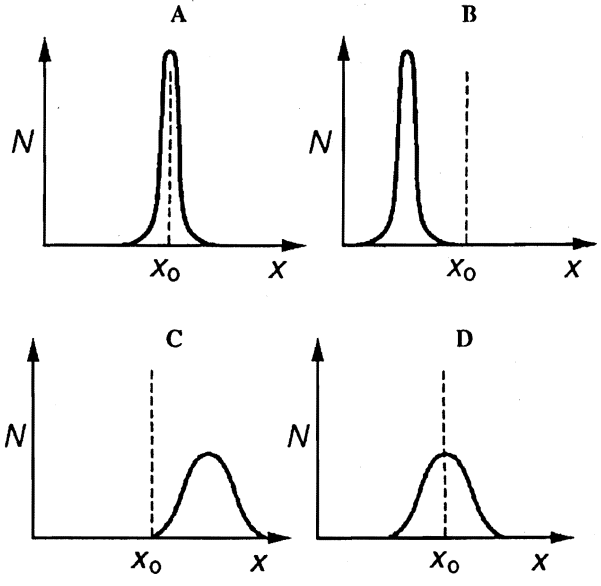
Which student obtained a set of results that could be described as precise but not accurate?

student	*results, g/ms*$^{-2}$			
A	9.81	9.79	9.84	9.83
B	9.81	10.12	9.89	8.94
C	9.45	9.21	8.99	8.76
D	8.45	8.46	8.50	8.41

N96/I/3

21 A quantity x is measured many times and the number N of measurements giving a value x is plotted against x. The true value of the quantity is x_0.

Which graph best represents precise measurements with poor accuracy?



N97/I/2

22 The density of the material of a rectangular block was determined by measuring the mass and linear dimensions of the block. The table shows the results obtained, together with their uncertainties.

mass = (25.0 ± 0.1) g
length = (5.00 ± 0.01) cm
breadth = (2.00 ± 0.01) cm
height = (1.00 ± 0.01) cm

The density was calculated to be 2.50 g cm^{-3}.

What was the uncertainty in this result?

A ± 0.01 g cm^{-3}
B ± 0.02 g cm^{-3}
C ± 0.05 g cm^{-3}
D ± 0.13 g cm^{-3}

N98/I/2

23 A micrometer, reading to ±0.01 mm, gives the following results when used to measure the diameter d of a uniform wire:

1.02 mm 1.02 mm 1.01 mm 1.02 mm 1.02 mm

When the wire is removed and the jaws are closed, a reading of –0.02 mm is obtained.

Which of the following gives the value of d with a precision appropriate to the micrometer?

A 1.0 mm **C** 1.038 mm
B 1.00 mm **D** 1.04 mm

J2000/I/2

24 The equation governing the volume rate of flow, V/t, of a fluid under streamline conditions through a horizontal pipe of length l and radius r is

$$V/t = (\pi p r^4)/(8l\eta),$$

where p is the pressure difference across the pipe and η is the viscosity of the fluid.

In an experiment to find η for water, a student quotes his result as 1.137×10^{-3} kg m^{-1} s^{-1} and estimates the percentage uncertainties in his measurements of V/t, p, l, and r as ±3%, ±2%, ±0.5% and ±5% respectively. How should he have written the value? J76/I/1

25 A student, wishing to determine the area of cross-section of a wire, takes a single reading of its diameter with a micrometer screw gauge, obtaining a value of 0.19 mm. He records the area of cross-section as 0.02835 mm^2. Assuming that his reading of the diameter is subject to an estimated uncertainty of ±0.01 mm, how should he have written the result for the area? Give *two* reasons why it would have better experimental practice to take the average of several diameter readings. N83/I/1

26 (i) What do the terms *systematic error* and *random error* mean?

(ii) Describe two ways of minimising the uncertainty due to each type of error. [6] J89/II/1

27 The length of a piece of paper is measured as 297 ± 1 mm. Its width is measured as 209 ± 1 mm.

(a) What is the fractional uncertainty in its length?

(b) What is the percentage uncertainty in its length?

(c) What is the area of one side of the piece of paper? State your answer with its uncertainty. [5] N89/II/2

Long Questions

28 *(a)* Fig. 1 shows a metric micrometer.

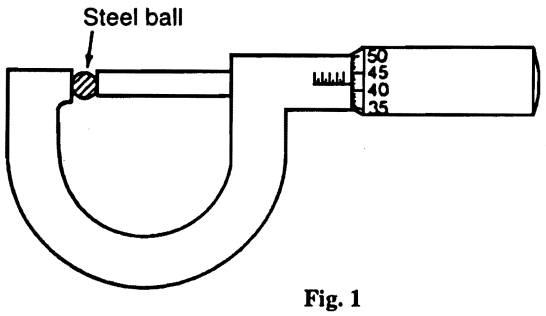


Fig. 1

(i) What is the reading on the micrometer scale?

(ii) What precautions would you take in using the micrometer to measure the diameter of the ball? Explain the reason for each.

(b) You are given a travelling microscope, a balance and some mercury. Explain how you would

(i) investigate the uniformity of the bore,

(ii) find the average diameter, of a long, glass capillary.

The travelling microscope may be read to ±0.1 mm. Discuss whether it would be possible to use this apparatus to detect a variation of 1% in the diameter of the tube between two points 25 mm apart. J74/I/1

29 A student measured the density of a metal cylinder by finding its dimensions with a ruler, which he could not read to better than ±1 mm because of parallax error, and its mass with a balance reading to ±0.1 g. He recorded his readings as follows:

diameter of cylinder = 20.0 mm
height of cylinder = 18.0 mm
mass of cylinder = 51.3 g,

from which he calculated:

density of cylinder = 9.072×10^3 kg m^{-3}.

(a) Explain which is meant by *parallax error*. How can it be reduced? [3 *marks*]

(b) With the given uncertainties in the readings, what is the percentage uncertainty in the value of the density? [4 *marks*]

(c) Comment on the student's choice of apparatus and the presentation of his results. (His arithmetic is correct.) How would you improve on his determination? [5 *marks*]

* The cylinder is placed in a vice and is compressed along its axis. Draw sketch-graphs to show how (i) the force exerted by the cylinder on the vice, (ii) the work done by the vice on the cylinder, vary as the cylinder is compressed. Account for the shapes of the graphs and explain the relationship between them. [8 *marks*] N75/I/1

30 *(a)* Distinguish between a *systematic* and a *random* error in the measurement of a physical quantity.

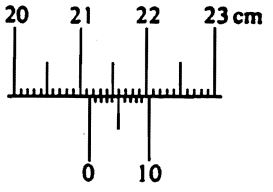


Fig. 2

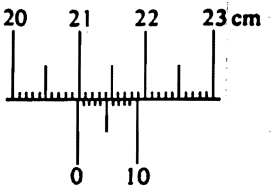


Fig. 3

A travelling microscope fitted with a vernier scale is used to measure the internal diameter of a capillary tube. Figs. 2 and 3 show the vernier when the microscope is adjusted so that the cross-wires are aligned at opposite ends of a diameter.

(i) Write down the two vernier readings.

(ii) What is the maximum uncertainty in a single reading of the vernier?

(iii) Hence find the maximum percentage uncertainty in the area of cross-section of the capillary that could arise if it were calculated from these two readings.

(iv) Explain why taking the mean of several microscope readings of the diameter tends to reduce, random error. J82/I/13(part)

31 Distinguish between a *random error* and a *systematic error* in the measurement of a physical quantity.

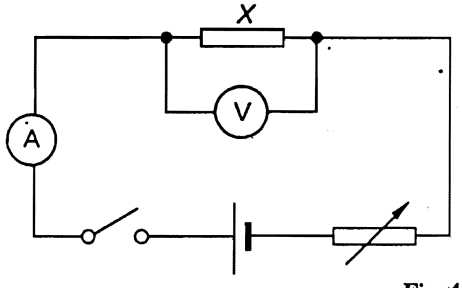


Fig. 4

The resistance X of an unknown resistor is measured by finding the potential difference across it and the current through it, using the circuit shown in Fig. 4.

(a) When the switch is closed and the variable resistor is at a certain setting, the readings of the meters are as shown in Figs. 5 and 6 below.

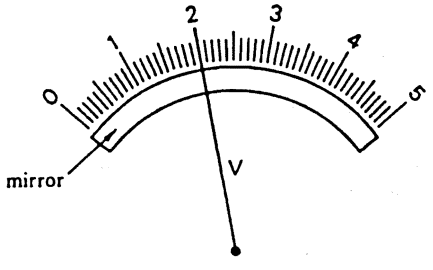


Fig. 5

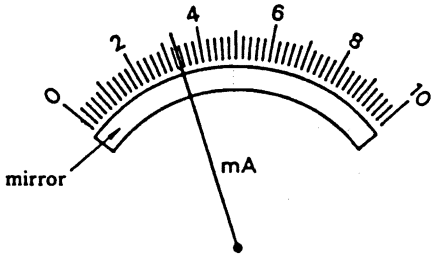


Fig. 6

Write down the readings of the voltmeter and of the milliammeter.

(b) Give an example of a systematic error that could occur in this experiment.

(c) Some meters have a strip of mirror mounted under the needle and near the scale, as shown in Figs. 5 and 6. Suggest how this may help to eliminate a possible source of error in the experiment.

(d) The variable resistor is adjusted to give a new set of readings which, when repeated, give average values of voltage V and current I of 3.00 ± 0.03 V and 4.9 ± 0.1 mA respectively.

(i) Estimate the percentage uncertainty in the value of the unknown resistance X as a result of the uncertainties in the average values of V and I.

(ii) Find the unknown resistance X and express it with its associated uncertainty to the appropriate number of significant figures.

(e) When an experiment like this is performed, rather than taking an average, it is common practice to adjust the variable resistor so as to provide several pairs of values of potential difference and current. These values are then plotted on a graph, from which the value of X may be deduced. Discuss the advantages of this procedure compared with the determination of X from a single pair of readings, as in *(a)* above.

* "The act of measuring any physical quantity disturbs the situation being observed." This statement was made in connection with the measurement of position and momentum on an atomic scale. Discuss briefly whether the measurement of current and voltage in this experiment could be said to disturb the situation being observed. N86/II/8

32 *(a)* Distinguish between a *random error* and a *systematic error* in the measurement of a physical quantity. [2]

(b) The spring constant k of a spring may be determined by finding the extension of the spring and the load applied, using the apparatus shown in Fig. 7.

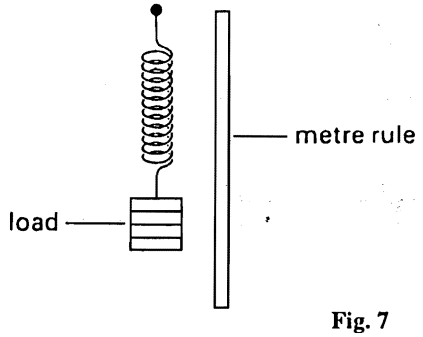


Fig. 7

(i) Give one example of a systematic error and one example of a random error which could occur in this experiment.

(ii) Readings of the position of the lower end of the spring are made using the metre rule. Suggest a method by which the error in these readings may be kept to a minimum. [4]

N91/III/1 (part)

33 *(a)* What is meant by

(i) a *systematic* error,

(ii) a *random* error? [2]

(b) A student set up the circuit shown in Fig. 8 in order to determine the resistance of a wire and hence the resistivity of the metal of the wire.

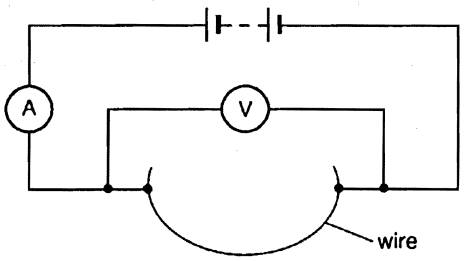


Fig. 8

The ammeter and voltmeter were both digital.

(i) State one possible random error which could occur in the use of the digital meters. How could this error be kept to a minimum?

* (ii) Explain why the voltmeter must have a resistance much greater than that of the wire in order to avoid a systematic error in the use of the ammeter. [5]

(c) The following readings were obtained for the experiment in *(b)*.

Reading of voltmeter = 1.30 ± 0.01 V
Reading of ammeter = 0.76 ± 0.01 A
Length of wire = 75.4 ± 0.2 cm
Diameter of wire = 0.54 ± 0.02 mm

Calculate, with its actual uncertainty, the value of

(i) the resistance of the wire,

(ii) the resistivity of the metal of the wire,

expressing your results to an appropriate number of significant figures. [8]

**(d)* A second student repeated the experiment in *(b)* with the same length of wire. In this new experiment, the supply voltage was varied and pairs of corresponding readings of the voltmeter and ammeter were tabulated. A graph showing the variation of current in the wire with p.d. across the wire was then plotted. Discuss the advantages of this procedure for the determination of resistance as compared with that used in *(c)*. [5]

N95/III/1

Cathode Ray Oscilloscope (Measurements)

34 A cathode-ray oscilloscope is fitted with a graticule ruled in cm. The Y-sensitivity is set at 10 V cm^{-1} and the time-base at 0.5 ms cm^{-1}. When an alternating e.m.f. is applied to the *Y*-input the wave trace obtained is as shown in the diagram (Fig. 9).

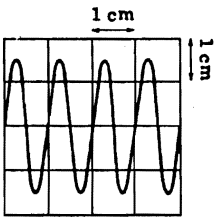


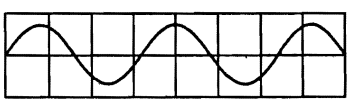
Fig. 9

Which one of the following correctly gives both the peak e.m.f. and the frequency of the e.m.f.?

	peak e.m.f./V	*frequency*/Hz
A	15	5000
B	15	2000
C	30	5000
D	30	2000
E	30	500

J81/II/21

35 The diagram below shows the trace on an oscilloscope screen when a sinusoidal signal was applied to the Y-plates.

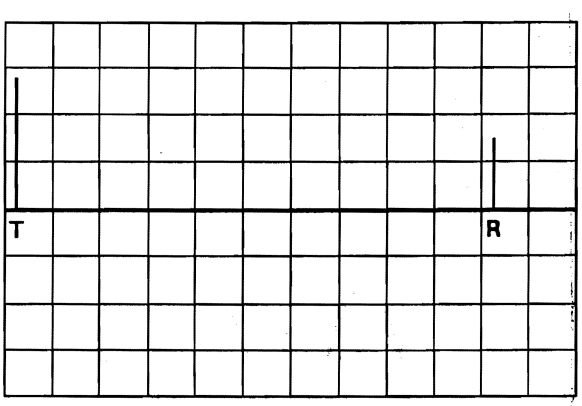


Given that the linear time base was set to 2.00 ms per division, what was the frequency of the signal?

A 62.5 Hz
B 156 Hz
C 312 Hz
D 625 Hz
E 1250 Hz

J88/I/9

36 A radio pulse is transmitted vertically upwards to measure the height of the ionosphere (the reflecting layer in the Earth's upper atmosphere). The outgoing pulse **T**, and its reflection **R** from the ionosphere, are recorded on the screen of an oscilloscope with time-base set at 50 μs per division.



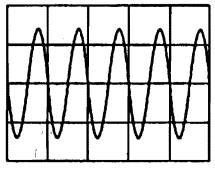
Given that the speed of radio waves is 3.0×10^8 m s^{-1}, what is the approximate height of the ionosphere?

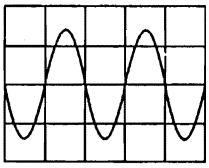
A 6.5 km
B 7.5 km
C 13 km
D 15 km
E 75 km

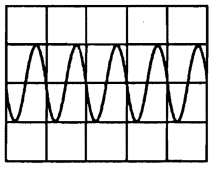
N91/I/3

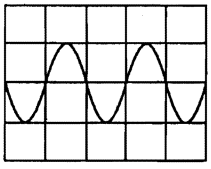
37 The Y-input terminals of an oscilloscope are connected to a supply of peak value 5.0 V and of frequency 50 Hz. The time-base is set at 10 ms per division and the Y-gain at 5 V per division.

Which trace could be obtained?

A 

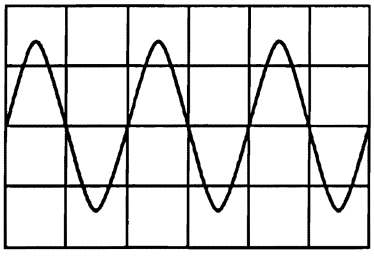
B 

C 

D 

J92/I/27; N2000/I/2

38 An alternating p.d. is applied across the Y-plates of a cathode-ray oscilloscope (c.r.o.) and produces the trace shown below.

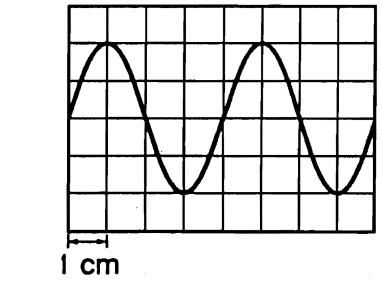


If the peak voltage of the alternating p.d. is 2.8 V and its frequency is 50 Hz, what are the time-base and Y-gain settings of the c.r.o.?

	time-base setting	Y-*gain*
A	10 μs cm^{-1}	2.0 V cm^{-1}
B	20 μs cm^{-1}	1.0 V cm^{-1}
C	10 ms cm^{-1}	2.0 V cm^{-1}
D	20 ms cm^{-1}	1.0 V cm^{-1}

J94/I/27

39 The trace shown appeared on an oscilloscope screen with the time-base set to 2.0 ms cm^{-1}.



What was the frequency of the signal?

A	40 Hz	**C**	250 Hz
B	125 Hz	**D**	500 Hz

J97/I/2

Long Questions

40 *(c)* The screen of a cathode-ray tube in one particular make of television is 45.0 cm wide. In order that an acceptable picture is formed on the screen, the electron beam sweeps across the screen 625 times for each picture and 25 pictures are displayed in each second. Calculate the value of the time-base, expressed in μs cm^{-1}, used in the cathode-ray tube. [4]

N93/III/3 (part)