GCE A LEVEL

1420U30-1

THURSDAY, 26 MAY 2022 – AFTERNOON

PHYSICS – A2 UNIT 3

OSCILLATIONS AND NUCLEI

2 hours 15 minutes plus your additional time allowance

Surname: ________________________________

First name(s): ________________________________

Centre Number: ________________________________

Candidate Number: 2 ________________________________

	For Examiner's use only		
	Question	Maximum Mark	Mark Awarded
SECTION A	1.	13	
	2.	14	
	3.	19	
	4.	13	
	5.	21	
SECTION B	6.	20	
	Total	100	

(Turn over)

ADDITIONAL MATERIALS

In addition to this examination paper you will require a calculator and a DATA BOOKLET, provided separately.

ITEMS INCLUDED WITH QUESTION PAPER

A separate Diagram Booklet.

The Diagram Booklet MUST be handed in to the invigilators and sent for marking.

(Turn over)

INSTRUCTIONS TO CANDIDATES

Use black ink, black ball – point pen, black felt tip or your usual method.

Write your name, centre number and candidate number in the spaces on the front cover.

Answer ALL questions.

**Write your answers in the spaces provided.
If you run out of space use the additional pages at the back of the booklet taking care to number the question(s) correctly.**

(Turn over)

INFORMATION FOR CANDIDATES

This paper is in 2 sections, A and B.

Section A: 80 marks. Answer ALL questions.
You are advised to spend about 1 hour 35 minutes, plus your additional time allowance, on this section.

Section B: 20 marks. Comprehension.
You are advised to spend about 40 minutes, plus your additional time allowance, on this section.

The number of marks is given in brackets at the end of each question or part – question.

The assessment of the quality of extended response (QER) will take place in question 3 (b).

SECTION A

ANSWER ALL QUESTIONS.

1. (a) Radon is a radioactive gas and emits alpha particles.

(i) Explain what is meant by the ACTIVITY of a radioactive source AND give its unit.

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[2 marks]

continued on the next page . . .

Question 1 (a) continued

1. (a) (ii) The half – life of radon is 3.3×10^5 s.

Determine the time it takes for a sample of radon to decay to 20% of its initial activity.

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[3 marks]

continued on the next page . . .

Question 1 (a) continued

1. (a) (iii) Discuss the extent to which alpha particles are a risk to the human body.

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[3 marks]

continued on the next page . . .

Question 1 continued

1. (b) Radium – 226 decays into radon.

$$^{226}_{88}\mathrm{Ra} \longrightarrow {}^{222}_{86}\mathrm{Rn} + {}^{4}_{2}\alpha$$

Assuming that 98% of the energy released in this process is converted to the kinetic energy of the alpha particle, use the data below to determine the speed of the alpha particle.

Atomic masses:

$^{226}_{88}\mathrm{Ra} = 226.025\,410\ \mathrm{u}$

$^{4}_{2}\mathrm{He} = 4.002\,603\ \mathrm{u}$

$1\ \mathrm{u} = 931\ \mathrm{MeV}$

$^{222}_{86}\mathrm{Rn} = 222.017\,578\ \mathrm{u}$

$m_{\mathrm{electron}} = 0.000\,549\ \mathrm{u}$

continued on the next page . . .

Question 1 (b) continued

(Turn over)

[5 marks]

(Total for Question 1 = 13 marks)

(Turn over)

2. A balloon of volume 1.60×10^{-3} m^3 contains helium at a pressure of 1.20×10^5 Pa and a temperature of 293 K.

(Relative molecular mass of helium = 4)

(a) Determine:

(i) the number of molecules in the balloon;

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[2 marks]

continued on the next page . . .

Question 2 (a) continued

2. (a) (ii) the rms speed of the molecules.

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[2 marks]

continued on the next page . . .

Question 2 continued

2. (b) The product of the pressure and the volume of the gas is given by $pV = nRT$ and also by $pV = \frac{1}{3}Nm\overline{c^2}$

(i) Show that the mean kinetic energy of a gas molecule is $\frac{3}{2}kT$ where k is the Boltzmann constant.

(Turn over)

[4 marks]

2. (b) (ii) Calculate the mean kinetic energy of a molecule in the gas.

[1 mark]

continued on the next page . . .

Question 2 (b) continued

2. (b) (iii) Determine the internal energy of the gas in the balloon.

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[1 mark]

continued on the next page . . .

Question 2 continued

2. (c) (i) Explain, in terms of the molecules, the difference in the nature of the INTERNAL ENERGY in an ideal gas and in a liquid.

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[3 marks]

continued on the next page . . .

Question 2 (c) continued

2. (c) (ii) State the temperature of a system for its internal energy to be a minimum.

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[1 mark]

(Total for Question 2 = 14 marks)

3. **Look at the diagram for Question 3 in the separate Diagram Booklet. The diagram is a graph.**

A small object of mass 0.30 kg oscillates at the end of a spring. The graph shows how its acceleration, *a*, depends on its displacement, *x*, from a fixed point.

(a) (i) Identify the TWO characteristics OF THE GRAPH that show that the object is oscillating with SIMPLE HARMONIC MOTION.

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[2 marks]

continued on the next page . . .

Question 3 (a) continued

3. (a) (ii) Use the graph to show that the angular frequency, ω, of the oscillation is approximately 7.7 rad s^{-1}.

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[3 marks]

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Question 3 (a) continued

3. (a) (iii) Calculate:

I. the period of oscillation;

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[1 mark]

II. the spring constant;

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[2 marks]

continued on the next page . . .

Question 3 (a) (iii) continued

3. (a) (iii) III. the velocity of the object as it passes through the centre of oscillation.

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[2 marks]

continued on the next page . . .

Question 3 (a) continued

3. (a) (iv) Look at the diagram for Question 3 (a) (iv) in the separate Diagram Booklet.
The diagram shows a set of axes for energy against time.

The object was released at the displacement of -0.05 m at time $t = 0$. On the axes sketch:

I. the potential energy of the system (label the sketch PE),

II. the kinetic energy of the system (label the sketch KE).

Draw both sketches OVER ONE CYCLE of the undamped oscillation. (No values are required on the axes.)

[3 marks]

continued on the next page . . .

Question 3 continued

3. (b) Explain what is meant by the terms DAMPING and RESONANCE AND discuss their importance in real systems giving an example for each.

(Turn over)

[6 marks QER]

(Total for Question 3 = 19 marks)

(Turn over)

4. A satellite orbiting the Earth completes one revolution in 105 minutes.

Mass of the Earth $= 6.0 \times 10^{24}$ kg,

radius of the Earth $= 6\,400$ km

(a) Explain what is meant by the term RADIAN.

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[2 marks]

continued on the next page . . .

(Turn over)

Question 4 continued

4. (b) Calculate the satellite's angular velocity, ω, in rad s^{-1}.

[3 marks]

continued on the next page . . .

Question 4 continued

4. (c) The gravitational force on the satellite is given by $\frac{GM_E m}{R^2}$ where m is the mass of the satellite, M_E is the mass of the Earth and R is the radius of the orbit.

Show that:

$$R = \sqrt[3]{\frac{GM_E}{\omega^2}}$$

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[2 marks]

4. (d) Determine the height of the satellite above the surface of the Earth.

[3 marks]

continued on the next page . . .

Question 4 continued

4. (e) The mass of the Moon is 7.3×10^{22} kg and its radius is 1 740 km.

Discuss whether a satellite would be able to orbit the Moon with a period of 105 minutes.

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[3 marks]

(Total for Question 4 = 13 marks)

5. A student says that the radiation intensity, I, of gamma rays increases with decreasing distance, r, from a source such that:

$$I \propto \frac{1}{r^n}$$

She wishes to determine the value of n.

Look at the diagram for Question 5
in the separate Diagram Booklet.
The diagram shows the arrangement of apparatus used by the student.

The student uses a source of alpha, beta and gamma radiation. She measures the intensity of the rays at set distances from the source by determining the count over intervals of one minute. She also takes measurements without the source at the start and at the end of the experiment.

continued on the next page . . .

Question 5 continued

5. (a) (i) Suggest why a thin aluminium plate is placed near the source.

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[1 mark]

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(Turn over)

Question 5 (a) continued

5. (a) (ii) Explain why readings are taken without the source, at the start AND at the end of the experiment.

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[2 marks]

continued on the next page . . .

Question 5 continued

5. (b) Look at the table for Question 5 (b) in the separate Diagram Booklet.

At each distance, *r*, the counts were measured over one minute intervals three times. The uncertainty in *r* is ± 0.005 m. The measurements are recorded in the table.

COMPLETE THE TABLE.

Space for calculations.

[2 marks]

continued on the next page . . .

Question 5 continued

5. (c) (i) Look at the table for Question 5 (c) (i) in the separate Diagram Booklet.

The student subtracts the mean count without the source from the mean count for each distance to obtain the corrected mean count, *N*.

She also determines the uncertainty in each of these corrected mean counts.

COMPLETE THE TABLE.

Space for calculations.

[2 marks]

continued on the next page . . .

Question 5 (c) continued

5. (c) (ii) Look at the diagram for Question 5 (c) (ii) in the separate Diagram Booklet.
The diagram is a grid.

On the grid, plot a graph of the corrected mean count, *N*, against distance, *r*.
ERROR BARS ARE NOT REQUIRED.

[3 marks]

(iii) The student claims that error bars may be shown on the graph for the corrected mean count, but not the distance. Justify her claim.
Calculations are not required.

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[1 mark]

continued on the next page . . .

Question 5 continued

5. (d) Her friend suggests using a logarithmic graph. She calculates the logarithmic values in the table below.

Distance, r / m	$\ln r$	$\ln N$
1.000	0.00	4.63
0.800	–0.22	5.06
0.600	–0.51	5.61
0.400	–0.92	6.42

Look at the diagram for Question 5 (d) in the separate Diagram Booklet.
The diagram shows the data plotted on the graph.

continued on the next page . . .

Question 5 (d) continued

For a distance of $r = 1.000$ m use the table in part (c) to show that the uncertainty in the logarithmic counts for this distance is approximately 0.15

[3 marks]

continued on the next page . . .

Question 5 continued

5. (e) (i) Starting with intensity:

$$I \propto \frac{1}{r^n}$$

justify how the logarithmic graph can be used to determine n.

[3 marks]

(Turn over)

Question 5 (e) continued

5. (e) (ii) Use the maximum and minimum gradients to determine n and the ABSOLUTE uncertainty in its value.

[4 marks]

(Total for Question 5 = 21 marks)

TOTAL FOR SECTION A = 80 marks

SECTION B

ANSWER ALL QUESTIONS.

6. Read through the following article carefully.

HOW DO YOU PRODUCE REALLY LOW TEMPERATURES AND CAN YOU THEN DO SOME COOL STUFF WITH IT?

Paragraph 1

Look at FIGURE 1 for Question 6 in the separate Diagram Booklet.

The first thing you have to do is to produce low temperatures and this is usually achieved by taking a gas through a closed cycle such as that shown in FIGURE 1.

continued on the next page . . .

Question 6 continued

Paragraph 2

1. **Air, initially under high pressure, is expanded at constant temperature.**
2. **Heat is allowed to escape at constant volume.**
3. **The gas is compressed at a constant low temperature.**
4. **The gas is heated at constant volume to a high pressure.**

Paragraph 3

The end result is that the gas does a large amount of work in each cycle. This means that the gas must have heat flowing into it leading to the cooling of whatever it is that requires cooling.

continued on the next page . . .

Question 6 continued

Paragraph 4

A different and simpler method of cooling gases is called the Joule – Thompson method, which does not involve a gas going through a cycle. A gas is compressed to a pressure of two thousand times atmospheric pressure. The gas is then allowed to cool back to room temperature. After that, it is allowed to expand quickly through a nozzle to atmospheric pressure leading to a tremendous amount of further cooling. In the expansion, the gas does a very large amount of work but the non – ideal gas molecules also have an enormous increase in potential energy because of the attractive forces between molecules. Both these factors cool the gas by a huge factor.

continued on the next page . . .

Question 6 continued

Paragraph 5

Okay, so now we have the basic physics for producing low temperatures. Apply this low temperature to air and we can make a product that can give hours of fun – liquid nitrogen (LN_2).

Paragraph 6

Most of the fun that can be obtained from LN_2 is based on the fact that it boils at a temperature of $-195.8^{\circ}C$ and, in doing so, expands by a factor of approximately 1 000. For example, a cool rotating rocket can be built using a simple plastic water bottle.

continued on the next page . . .

Question 6 continued

Paragraph 7

Look at the FIGURE 2 for Question 6 in the separate Diagram Booklet.

The boiling nitrogen makes the nozzle of the plastic water bottle into a jet engine. When you then place the plastic water bottle on a nicely polished wooden floor it will rotate far more quickly than you would ever anticipate, providing a great demonstration for even the most ardent physics – hating pupil. What can be even more spectacular is when the bottle accidentally hits something solid (like the leg of a lab desk). The wall of the plastic water bottle will be at around $-200°C$ and fragile. This, combined with the high pressure inside the bottle, leads to rather a loud and impressive bang.

continued on the next page . . .

Question 6 continued

Paragraph 8

Although LN_2 can be fun, it can also be dangerous. For instance, when transporting a large, open container of LN_2 (Look at FIGURE 3 for Question 6 in the separate Diagram Booklet), you should not remain in the confined space of a lift with the container in case the lift becomes stuck. Most of the danger from LN_2 arises from its 200°C temperature difference from its surroundings. Nonetheless, it is always amusing when TV chefs wear safety goggles and gloves when making ice cream using LN_2 but never bother with any safety equipment when using litres of boiling fat above a gas fire.

continued on the next page . . .

Question 6 continued

Paragraph 8 continued

I promise you that the boiling fat is far more dangerous even though the temperature difference, compared with human body temperature, is around 200°C for both LN_2 and boiling fat.

Paragraph 9

In conclusion, low temperatures and LN_2 can be dangerous for some obvious reasons but they can also lead to some amusement and even some Michelin – starred ice cream.

continued on the next page . . .

(Turn over)

Question 6 continued

Answer the following questions in your own words. Direct quotes from the original article will not be awarded marks.

6. (a) Look at the diagram for Question 6 (a) in the separate Diagram Booklet.

LABEL THE DIAGRAM with the processes 1 – 4 along with an arrow to show the direction of the cycle (see paragraph 2).

[2 marks]

continued on the next page . . .

Question 6 continued

6. (b) The author states that work is done by the gas in the cycle. By considering the four stages of the cycle, explain whether or not this statement is correct (see paragraph 3 and FIGURE 1).

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[2 marks]

continued on the next page . . .

Question 6 continued

6. (c) Estimate the work done during the cycle.

[3 marks]

continued on the next page . . .

Question 6 continued

6. (d) When a gas is compressed in a metal cylinder it will become hot. Explain why the gas will then cool to room temperature (see paragraph 4).

[2 marks]

continued on the next page . . .

Question 6 continued

6. (e) Explain whether or not the author is correct to state that the gas expanding quickly through the nozzle will cool greatly (see paragraph 4).

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[4 marks]

continued on the next page . . .

Question 6 continued

6. (f) Explain very briefly why nitrogen gas escapes through the nozzle of the plastic water bottle (see FIGURE 2 and paragraph 7).

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[1 mark]

continued on the next page . . .

Question 6 continued

6. (g) Look at the diagram for Question 6 (g) in the separate Diagram Booklet.

Starting from Newton's 3rd Law,

explain why the plastic water bottle shown will rotate anti – clockwise.

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[2 marks]

continued on the next page . . .

Question 6 continued

6. (h) An exploding bottle produces a "loud bang" (see paragraph 7). Explain briefly why this "loud bang" can be heard more than 100 m from the exploding bottle.

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[2 marks]

continued on the next page . . .

Question 6 continued

6. (i) Justify the author’s statement that it would be dangerous to share a confined space (like a lift) with a large container of liquid nitrogen (see paragraph 8 and FIGURE 3).

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[2 marks]

(Total for Question 6 = 20 marks)

TOTAL FOR SECTION B = 20 MARKS

END OF PAPER

TOTAL 100 MARKS

Question number	Additional pages, if required. Write the question number(s) in the left - hand margin.

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GCE A LEVEL

1420U30-1

THURSDAY, 26 MAY 2022 – AFTERNOON

PHYSICS – A2 UNIT 3

OSCILLATIONS AND NUCLEI

The Diagram Booklet MUST be handed in to the invigilators and sent for marking.

Diagram Booklet

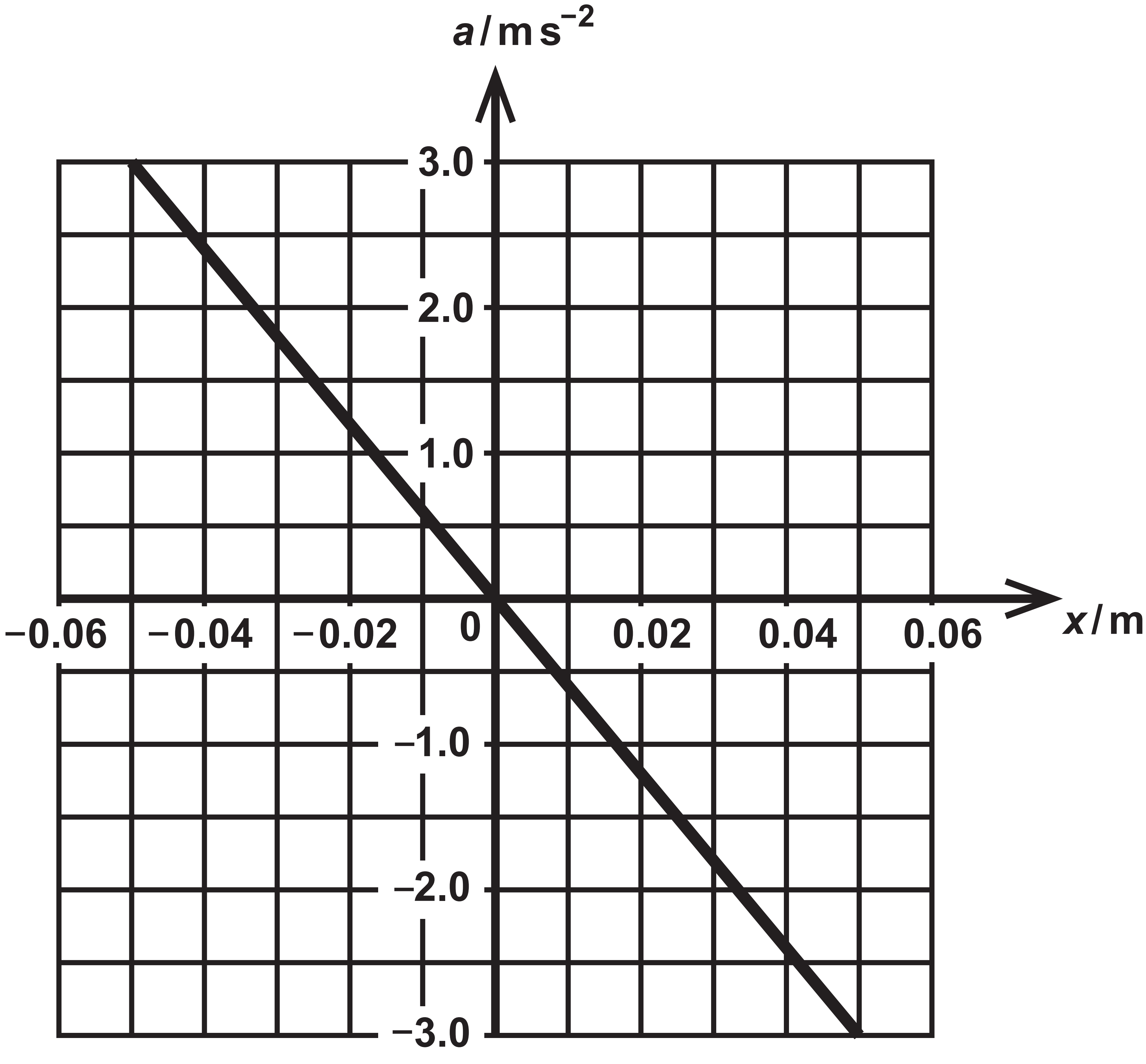
Surname: ______________________________

First name(s): ______________________________

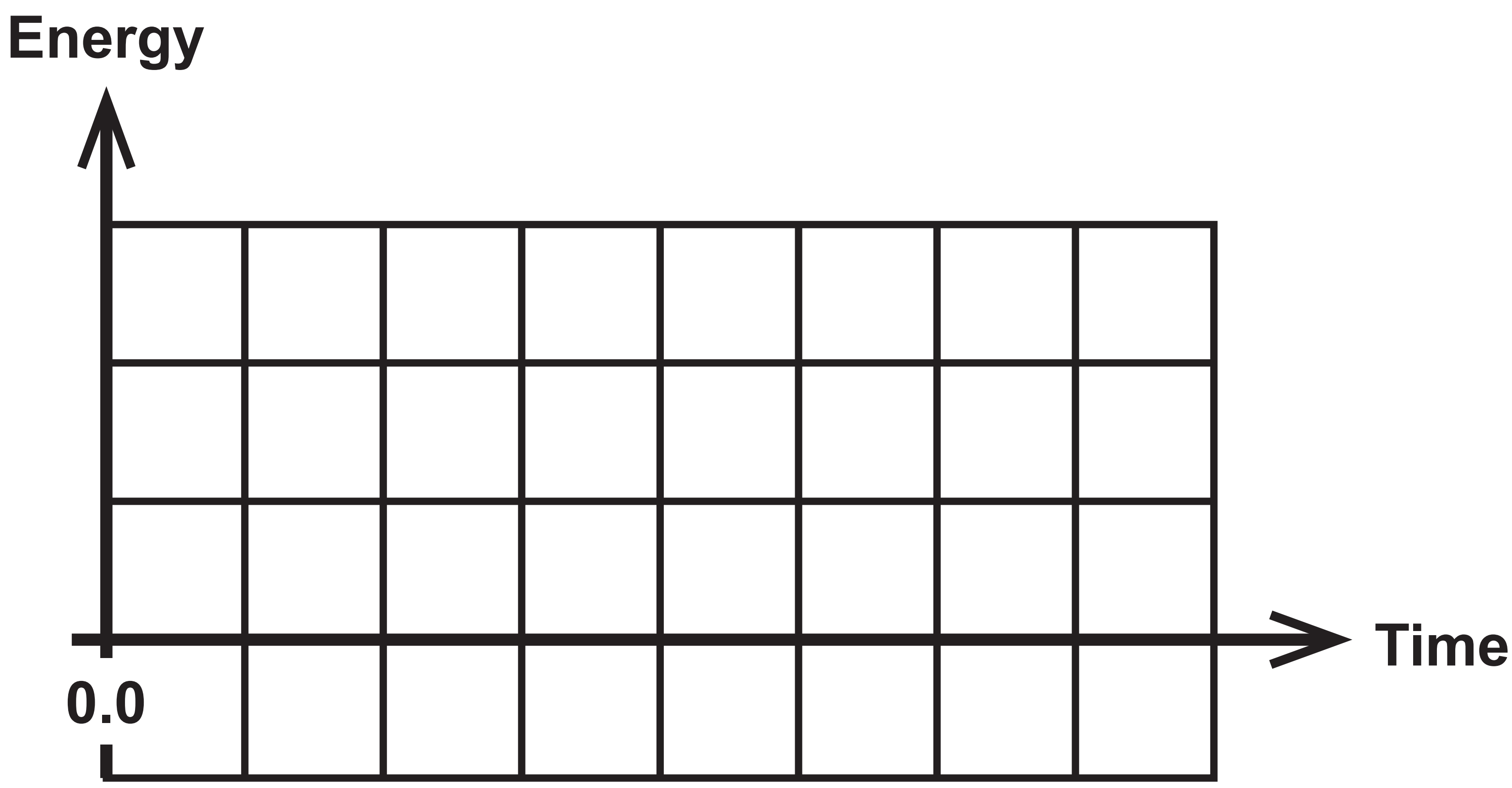
Centre Number: ______________________________

Candidate Number: 2 ______________________________

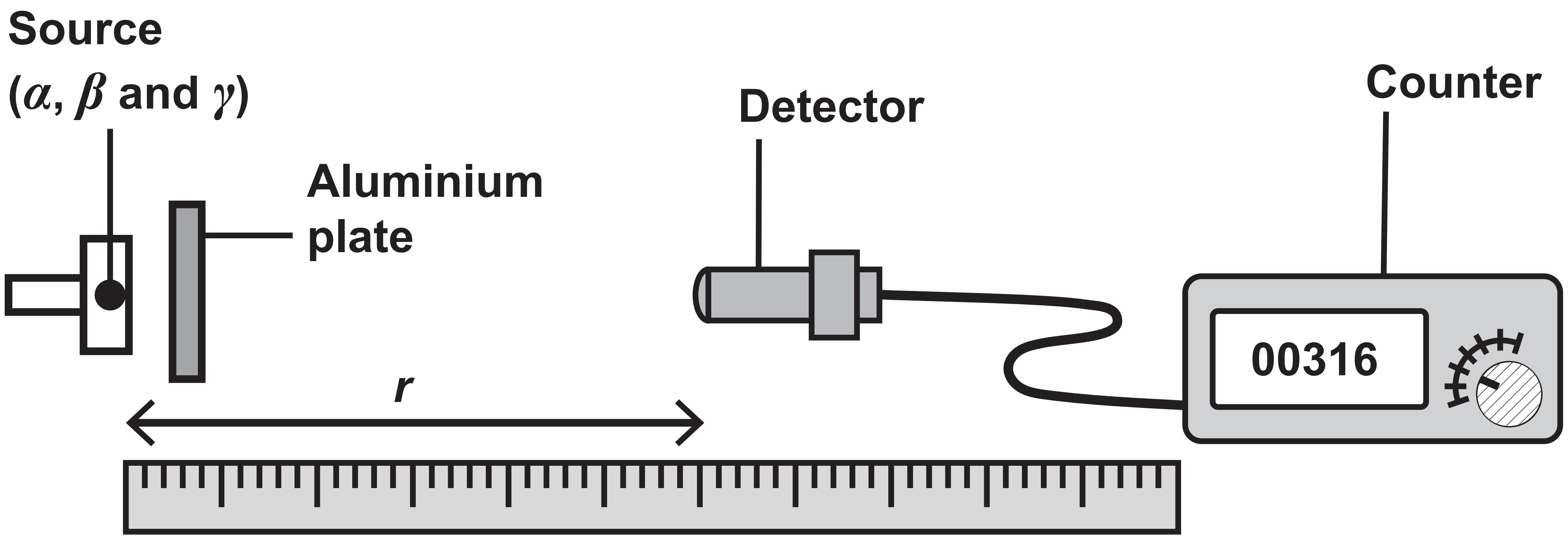
Question 3



Question 3 (a) (iv)



Question 5



Source
(α, β and γ)
Aluminium plate
Detector
Counter
00316
r

Question 5 (b)

Table

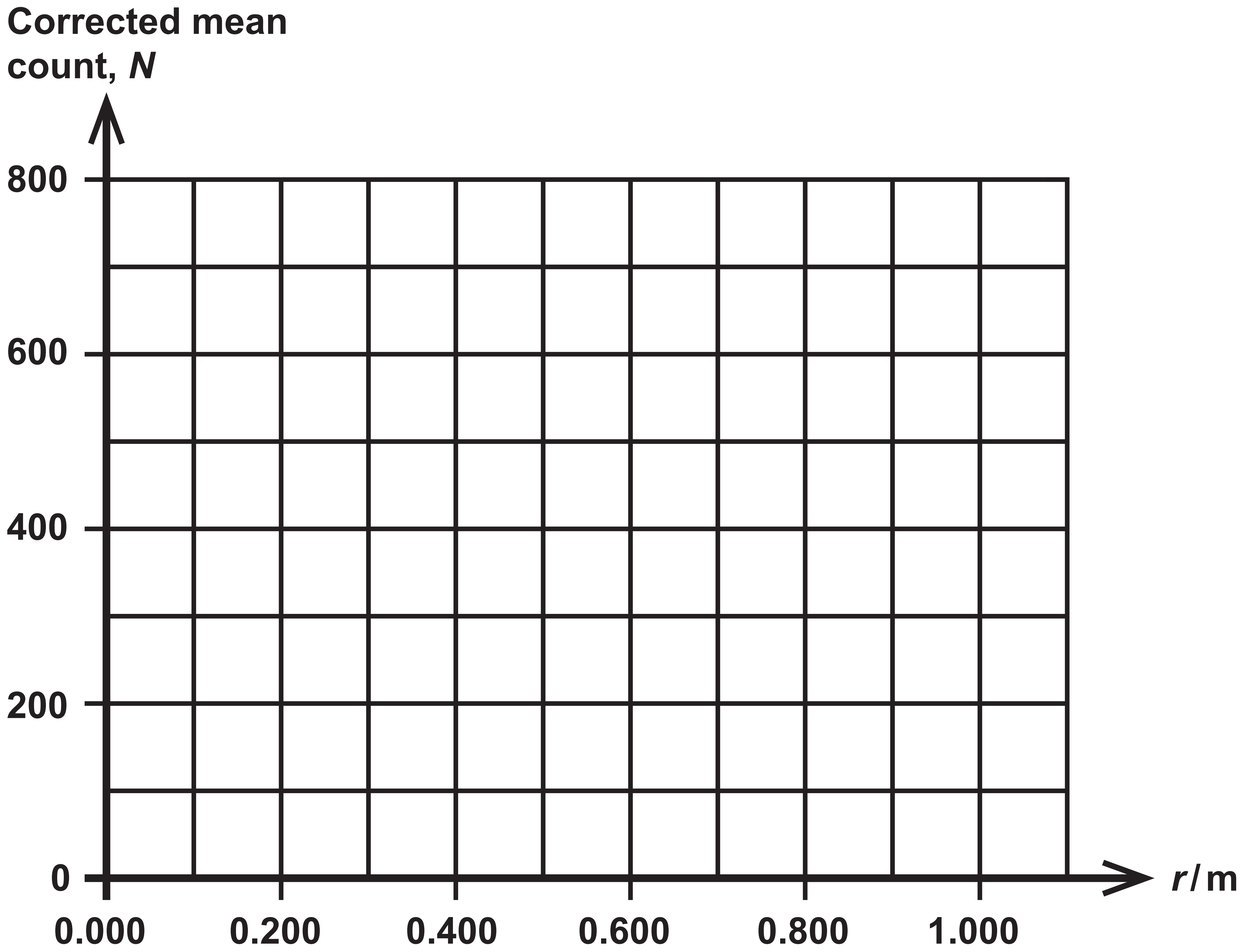
Distance, *r* / m	Count				Uncertainty in mean count
	First reading	Second reading	Third reading	Mean	
without source	19	22	25	22	3
1.000	110	130	136	125	13
0.800	195	165	178		
0.600	270	316	300		
0.400	661	604	651	639	29
without source	20	20	25	22	3

Question 5 (c) (i)

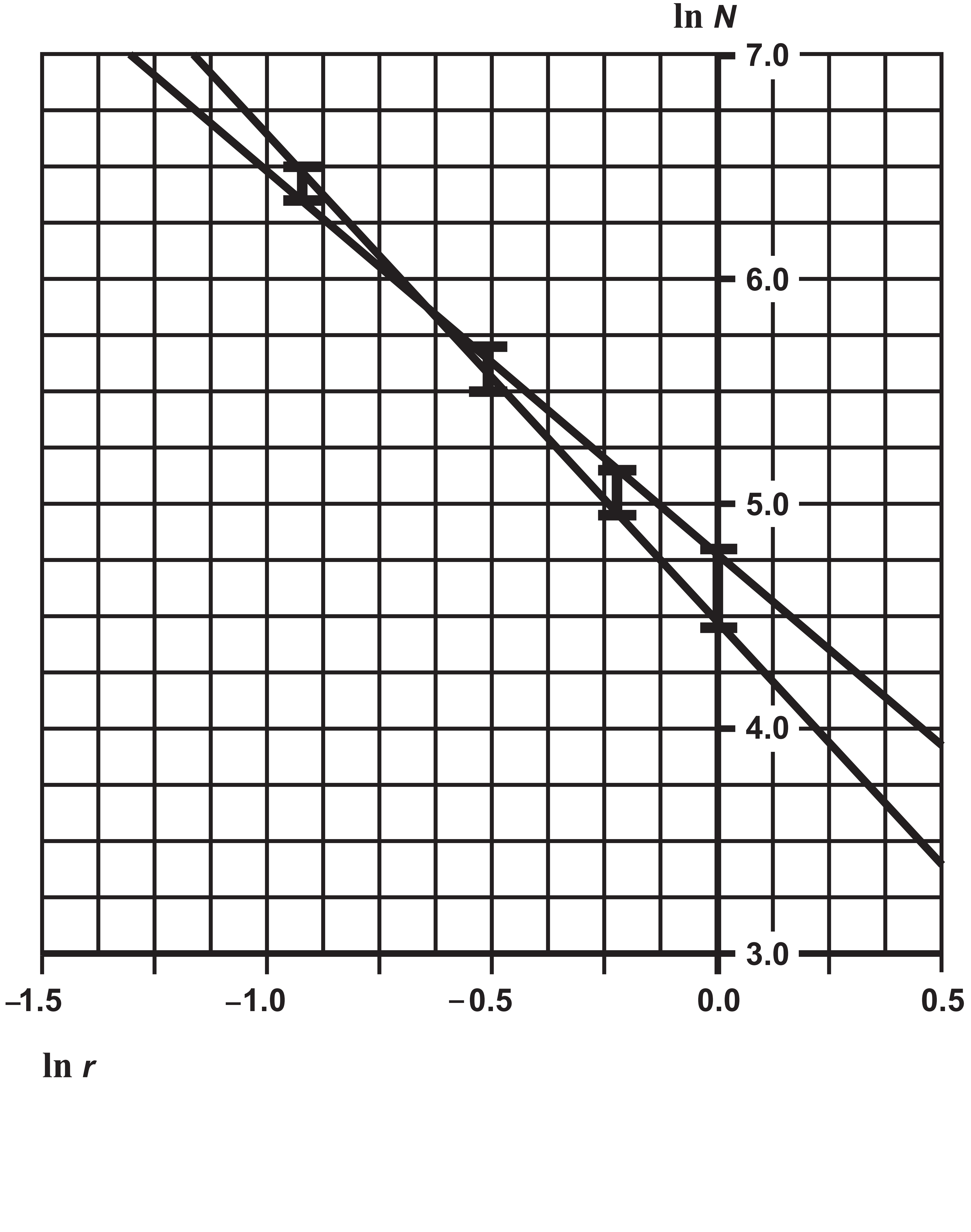
Table

Distance, r / m	Corrected mean count, N	Uncertainty in corrected mean count
1.000	103	16
0.800		
0.600		
0.400		

Question 5 (c) (ii)

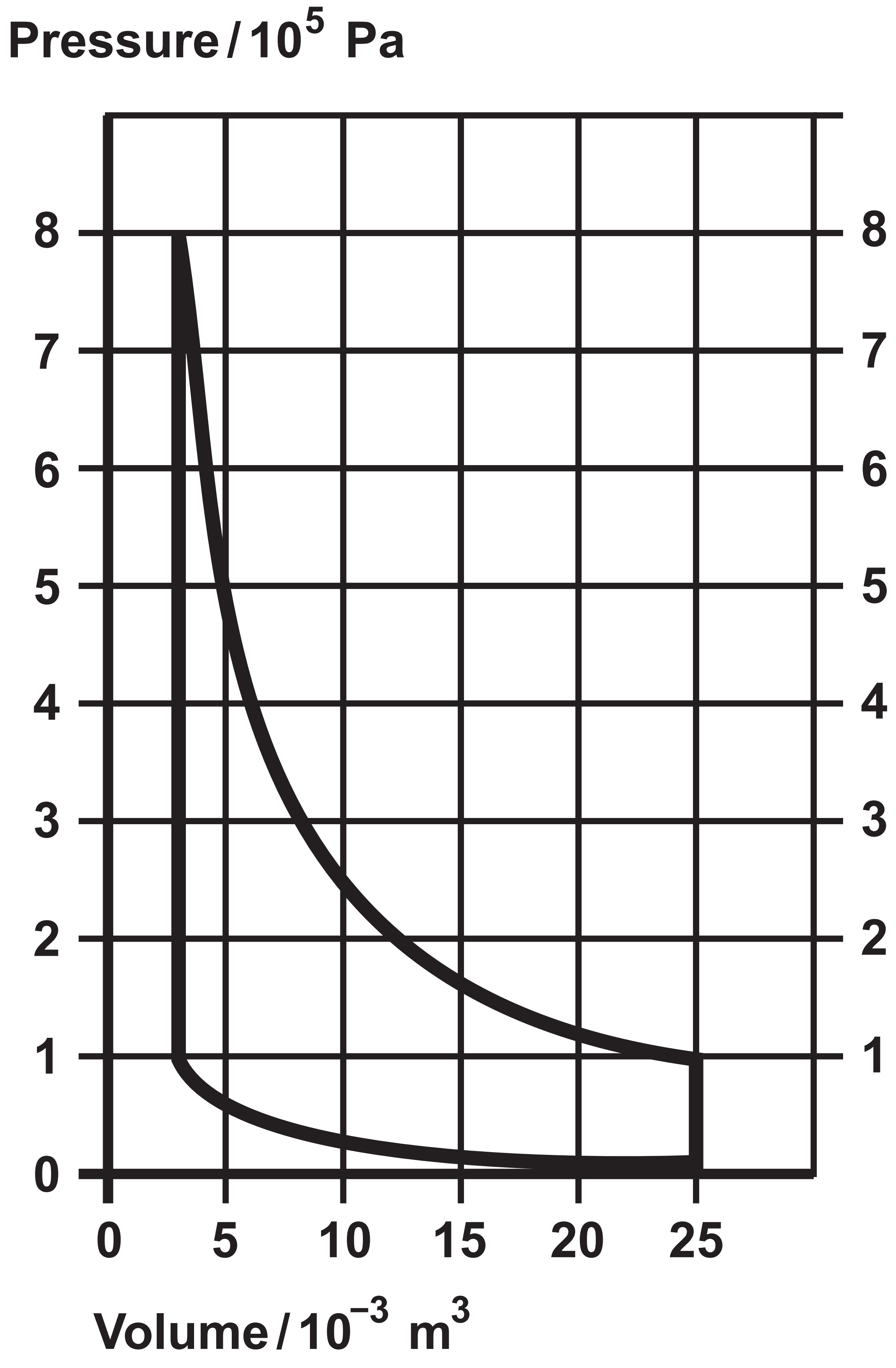


Question 5 (d)



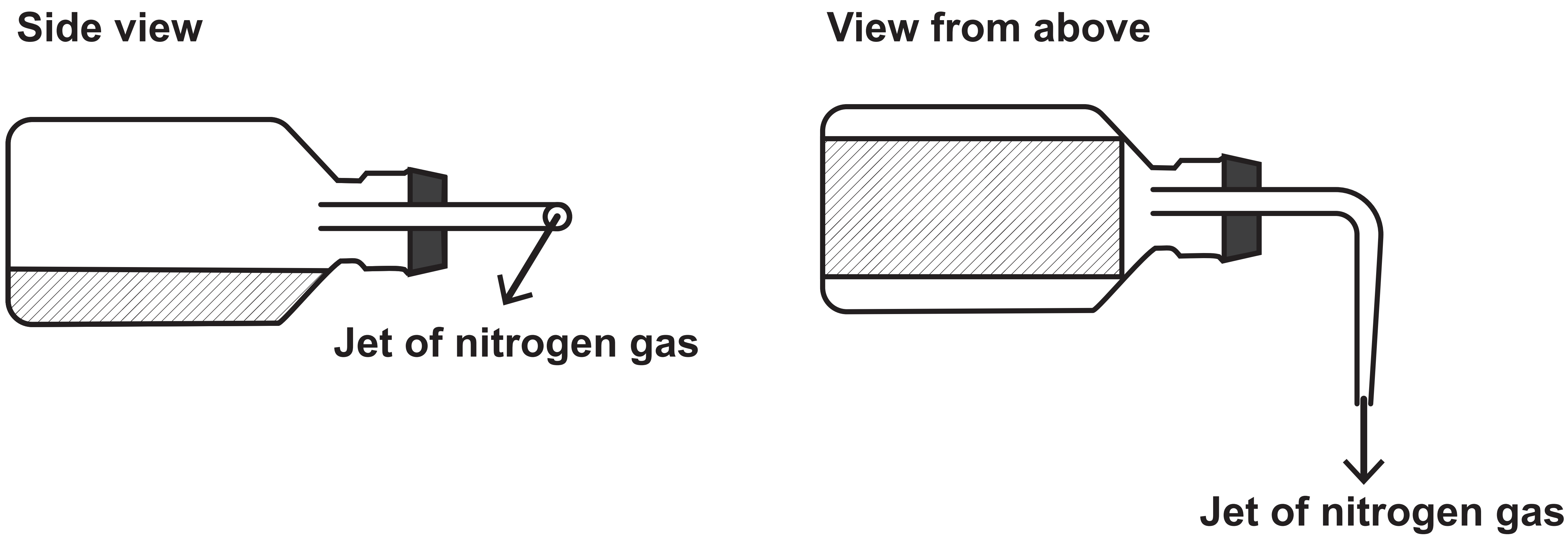
Question 6

FIGURE 1



Question 6

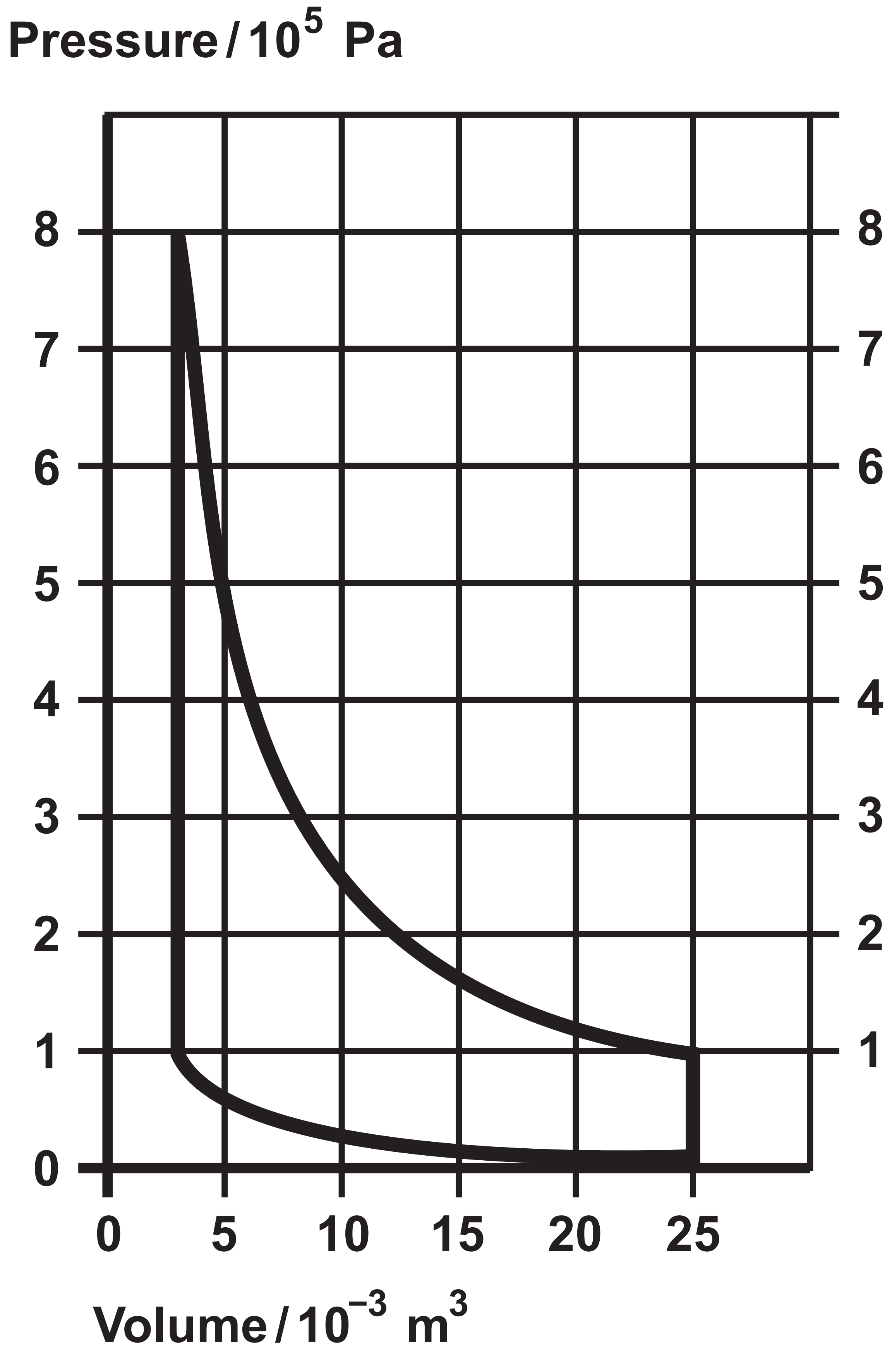
FIGURE 2



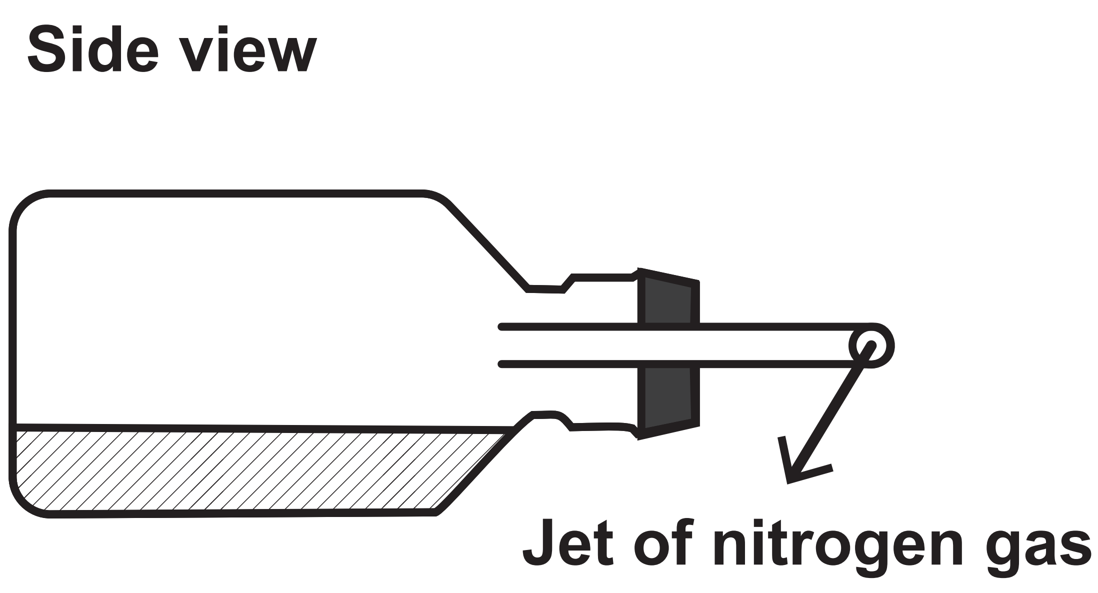
Question 6

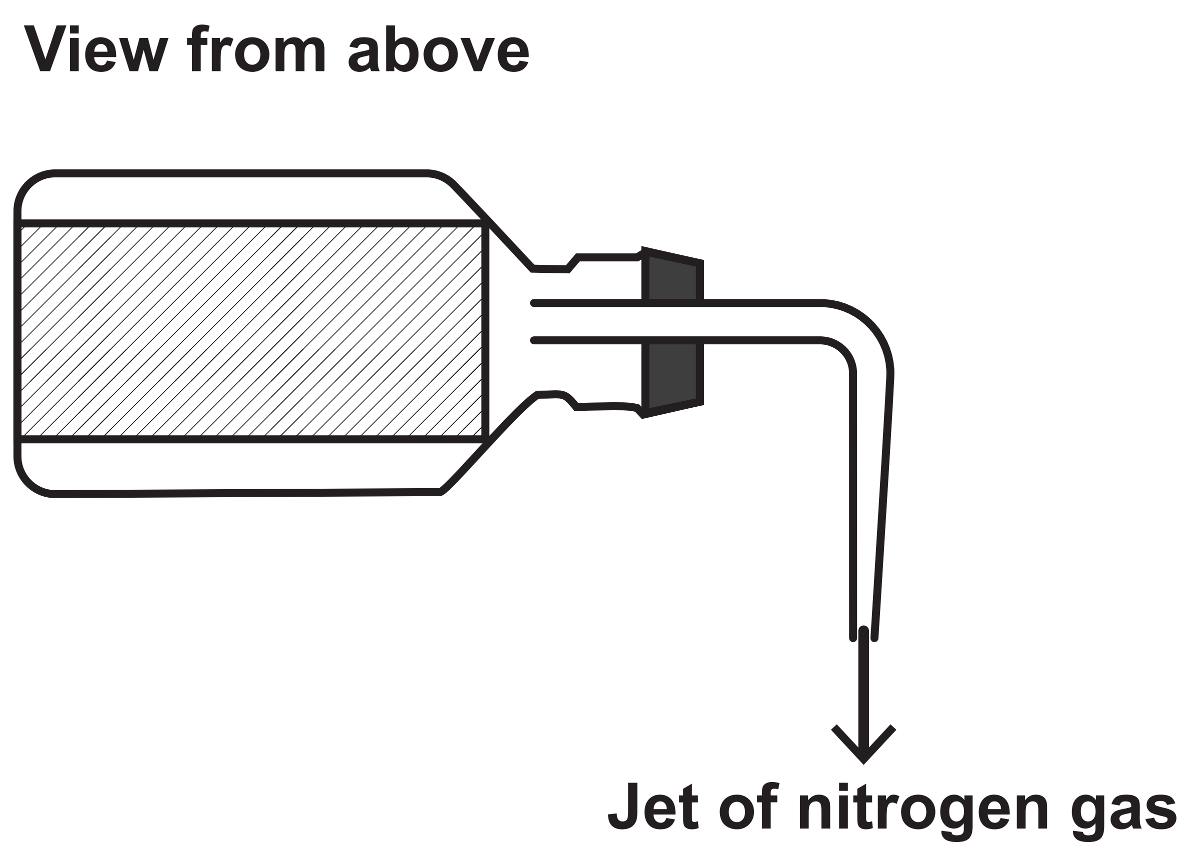
FIGURE 3

Question 6 (a)


Pressure / 10^5 Pa
8
7
6
5
4
3
2
1
0
8
7
6
5
4
3
2
1
0
5
10
15
20
25
Volume / 10^{-3} m^3

Question 6 (g)


Side view
Jet of nitrogen gas


View from above
Jet of nitrogen gas