



GCE A LEVEL



A420U10-1

THURSDAY, 26 MAY 2022 – AFTERNOON

PHYSICS – A LEVEL COMPONENT 1

NEWTONIAN PHYSICS

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.	11	
	2.	10	
	3.	13	
	4.	9	
	5.	17	
	6.	9	
	7.	11	
SECTION B	8.	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.

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.

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 7 (c).

SECTION A

ANSWER ALL QUESTIONS.

1. Look at the diagram for Question 1 in the separate Diagram Booklet.

In the diagram, a uniform plank, **AB**, of length **2.00 m** and weight **232 N** rests in equilibrium against a wall, at an angle of **55°** to the horizontal, as shown in the side view. The wall exerts a horizontal force, ***H***, on the plank. The floor is rough and exerts a force, ***P***, on the plank.

- (a) (i) **SHOW** the plank's **WEIGHT ON THE DIAGRAM** using a correctly placed arrow.

[1 mark]

continued on the next page . . .

(Turn over)

Question 1 (a) continued

1. (a) (ii) Show that H is approximately 80 N, giving a brief explanation of your method.

[4 marks]

continued on the next page . . .

(Turn over)

Question 1 (a) continued

1. (a) (iii) Write down the horizontal and vertical components of force P , and hence determine its magnitude and direction.

[3 marks]

continued on the next page . . .

(Turn over)

Question 1 continued

1. (b) The maximum frictional force that the floor can exert on the plank is **90 N**.
Show that the plank could not be in equilibrium at an angle of **45°** .

[3 marks]

(Total for Question 1 = 11 marks)

(Turn over)

2. Look at the diagram for Question 2 in the separate Diagram Booklet.

The diagram shows the apparatus used by Fatima for an investigation.

Fatima investigated the proportionality between force and acceleration using 7 metal discs, each of mass 0.100 kg, and a trolley. The runway was slightly tilted to compensate for friction.

She made measurements to determine the system's acceleration, a , with different numbers of discs hanging from the string. She put the spare discs (those not hanging from the string) securely on the trolley, so that the system's mass, M , was always the same. She plotted her values of acceleration, together with error bars, against hanging mass, m , on a grid.

continued on the next page . . .

Question 2 continued

2. (a) Explain why a is expected to be related

to m and M by the equation: $a = \frac{g}{M}m$

[1 mark]

- (b) Look at the diagram for Question 2 (b) in the separate Diagram Booklet.

The diagram shows the graph of Fatima's results.

Using the graph, determine the mass, M , of the SYSTEM, along with its ABSOLUTE uncertainty.

(Turn over)

continued on the next page . . .

(Turn over)

Question 2 continued

2. (c) Describe the measurements and calculations that Fatima might have made to determine the acceleration (for any one value of m).

Do NOT consider uncertainties.

[3 marks]

(Total for Question 2 = 10 marks)

(Turn over)

3. (a) (i) State the principle of conservation of momentum.

[2 marks]

- (ii) Look at the diagram for Question 3 (a) (ii) in the separate Diagram Booklet.
The diagram shows two metal discs.

A metal disc of mass 0.150 kg is sliding to the right at 2.40 m s^{-1} on a horizontal surface. It collides head – on with a disc of mass 0.300 kg which is initially stationary.

After the collision the 0.300 kg disc has a velocity of 1.40 m s^{-1} TO THE RIGHT.

continued on the next page . . .

(Turn over)

Question 3 (a) (ii) continued

- I. Determine the speed and direction of the 0.150 kg disc after the collision.**

[3 marks]

continued on the next page . . .

(Turn over)

Question 3 (a) (ii) continued

**II. Calculate the kinetic energy lost
in the collision.**

[2 marks]

**III. Explain how the principle of
conservation of energy applies
to this collision.**

[2 marks]

continued on the next page . . .

(Turn over)

Question 3 continued

- 3. (b) Look at the diagram for Question 3 (b) in the separate Diagram Booklet.**

Cedric wishes to investigate the collision experimentally. He plans to release the 0.150 kg disc from a distance, l , up a ramp. This is shown on the diagram.

He calculates that l needs to be GREATER THAN approximately 0.7 m for the disc to reach a speed of 2.40 m s^{-1} by the bottom.

Evaluate whether he is correct.

[4 marks]

(Total for Question 3 = 13 marks)

4. (a) Explain why an object moving in a circular path requires a resultant force to act on it, even when it is travelling at constant speed.

[2 marks]

- (b) Look at the diagram for Question 4 (b) in the separate Diagram Booklet.

Behind a safety screen in an engineering laboratory, a metal sphere of mass **0.200 kg** is whirled in a horizontal circle on the end of a thin steel rod.

continued on the next page . . .

(Turn over)

Question 4 (b) continued

- 4. (b) (i) The breaking stress of the steel under tension is 450 MPa and the ROD'S DIAMETER is 1.2 mm. Show that the greatest force that the rod can exert is roughly 500 N.**

[2 marks]

continued on the next page . . .

(Turn over)

Question 4 (b) continued

- 4. (b) (ii) Calculate the greatest rotation frequency (number of revolutions per second) at which the sphere can be whirled before the rod breaks.**

[3 marks]

continued on the next page . . .

(Turn over)

Question 4 (b) continued

4. (b) (iii) I. State an assumption that you have made (or factor that you have ignored) in your calculation for part (b) (ii).

[1 mark]

- II. Bearing in mind your previous answer, will the greatest rotation frequency before the rod breaks be larger or smaller than your calculated value?
Justify your answer briefly.

[1 mark]

(Total for Question 4 = 9 marks)

(Turn over)

5. (a) Look at the diagram for Question 5 (a) in the separate Diagram Booklet.

The three springs, **A**, **B**, **C**, shown in the diagrams are identical and of negligible mass.

Each spring has spring constant, k .

For the system on the left, the period of natural oscillations is T_1 .

For the system on the right, the period is T_2 .

Calculate the ratio $\frac{T_2}{T_1}$, giving your reasoning.

[3 marks]

continued on the next page . . .

(Turn over)

Question 5 continued

5. (b) In a separate experiment a mass hanging from a spring is displaced **UPWARDS** by **30 mm** from its equilibrium position and released at time $t = 0$.

It performs simple harmonic motion with a period of **1.20 s**.

- (i) Show that the maximum velocity of the mass is approximately **0.16 m s^{-1}** .

[2 marks]

continued on the next page . . .

(Turn over)

Question 5 (b) continued

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

The diagram is a grid.

SKETCH a velocity – time graph for the mass **ON THE GRID**.

[2 marks]

- (iii) Calculate the speed of the mass at $t = 3.50$ s.

[2 marks]

continued on the next page . . .

(Turn over)

Question 5 (b) continued

- 5. (b) (iv) Ursula thinks that the kinetic energy of the mass varies at a frequency of 1.67 Hz. Evaluate this claim.**

[2 marks]

continued on the next page . . .

(Turn over)

Question 5 continued

- 5. (c) Ursula modified the mass – spring system in part (b) so that its oscillations are significantly damped.**

- (i) Suggest what practical modification she might have made.**

[1 mark]

continued on the next page . . .

(Turn over)

Question 5 (c) continued

5. (c) (ii) Ursula measured the amplitude of the oscillations at equal time intervals.

Here are her results:

Amplitude / mm	30	24	19	15
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Evaluate whether or not these results are consistent with an exponential decay of the amplitude.

[2 marks]

continued on the next page . . .

(Turn over)

Question 5 continued

- 5. (d) The physics of damping has been used in designing car suspensions and suspension bridges for pedestrians. Compare the PURPOSES that damping serves in these two cases.**

[3 marks]

(Total for Question 5 = 17 marks)

(Turn over)

6. (a) Define pressure.

[1 mark]

continued on the next page . . .

(Turn over)

Question 6 continued

6. (b) A sealed canister contains **0.200 mol** of oxygen (relative molecular mass : **32.0**).
An identical canister contains **0.200 mol** of nitrogen (relative molecular mass : **28.0**) at the same temperature.
Giving your reasoning, determine these ratios:

(i)
$$\frac{\text{pressure of oxygen}}{\text{pressure of nitrogen}}$$

[2 marks]

continued on the next page . . .

(Turn over)

Question 6 (b) continued

6. (b) (ii)
$$\frac{\text{rms speed of oxygen molecules}}{\text{rms speed of nitrogen molecules}}$$

[2 marks]

continued on the next page . . .

(Turn over)

Question 6 continued

6. (c) (i) At the centre of the Sun the pressure is estimated to be $2.5 \times 10^{16} \text{ Pa}$, and the density, $1.6 \times 10^5 \text{ kg m}^{-3}$.

Calculate the rms speed of the particles in that region, treating them as molecules of an ideal gas.

[2 marks]

continued on the next page . . .

(Turn over)

Question 6 (c) continued

- 6. (c) (ii) State TWO reasons why the ideal gas kinetic theory is not likely to give accurate results in this case.**

[2 marks]

(Total for Question 6 = 9 marks)

(Turn over)

7. Look at the diagram for Question 7 in the separate Diagram Booklet.

The diagram shows three ways (AX, AY and AZ) in which 0.90 mol of an ideal gas can expand from a volume of 0.020 m^3 to a volume of 0.060 m^3 .

- (a) Calculate the temperatures at A and at X.

[3 marks]

continued on the next page . . .

(Turn over)

Question 7 continued

7. (b) Calculate the work done over AX .

[2 marks]

continued on the next page . . .

(Turn over)

Question 7 continued

7. (c) For both **AY** and **AZ** compare the work done, internal energy change and heat flow **WITH THOSE FOR AX**. Calculations are not wanted, but you must give your reasoning.

[illegible]

(Turn over)

[6 marks QER]

(Total for Question 7 = 11 marks)

TOTAL FOR SECTION A = 80

(Turn over)

SECTION B**ANSWER ALL QUESTIONS.**

8. Read through the following article carefully.

LASER DOPPLER COOLING**Paragraph 1**

Here, the laser and the humble Doppler shift combine to produce an incredibly cool effect, but what is Laser Doppler Cooling?

Paragraph 2

Perhaps the most obvious place to start is with the A level Doppler shift equation.

EQUATION 1

$$\frac{v}{c} = \frac{\Delta\lambda}{\lambda} = - \frac{\Delta f}{f}$$

continued on the next page . . .

(Turn over)

Question 8 continued**Paragraph 3**

This equation gives us the wavelength shift of light due to a moving source or a moving observer. The fractional change in wavelength, $\frac{\Delta\lambda}{\lambda}$, (or frequency, $\frac{\Delta f}{f}$ is just the ratio of the source's speed to the speed of light, $\frac{v}{c}$.

So, if a light source is moving at 1% of the speed of light, we get a 1% change in both the wavelength and the frequency of the light. This equation also applies to observers moving away from or toward a light source and starts to get particularly exciting when the observer just happens to be an atom.

continued on the next page . . .

Question 8 continued**Paragraph 4**

As an example, we can take a calcium atom in an ideal gas of calcium atoms at **300 K**.

So, the **rms** speed of a calcium atom can be calculated from the kinetic theory.

EQUATION 2

$$\frac{1}{2} m \overline{c^2} = \frac{3}{2} kT$$

continued on the next page . . .

Question 8 continued**Paragraph 5**

Knowing that the mass of a calcium atom is **40 u**, you get a speed of around **400 m s⁻¹**.

This means that when light approaches a calcium atom head – on, the calcium atom typically sees the light as being blue – shifted

by a fraction $\frac{400}{3 \times 10^8}$.

continued on the next page . . .

Question 8 continued**Paragraph 6**

Another important thing we just happen to know about calcium is that it has a red line in its emission (and absorption) spectrum.

The frequency of this red line is

456 000.6 GHz. We will then calculate the

blue – shifted frequency that a **400 m s⁻¹**

calcium atom sees when the atom has a

head – on collision with light of this frequency.

EQUATION 3

$$\Delta f = \frac{400}{3 \times 10^8} \times f \approx 0.6 \text{ GHz}$$

continued on the next page . . .

Question 8 continued**Paragraph 7**

So, when a calcium atom has a head – on collision with light of frequency **456 000.6 GHz**, the calcium atom says that the frequency of the light is **456 001.2 GHz**. It might seem that such a tiny difference would be completely unimportant. However, this difference is enough to stop the atom from absorbing the light. The light passes straight through the atom and no momentum is transferred to the atom. But when the frequency of the light is exactly right, you can get absorption. To get this frequency exactly right we use light of frequency **456 000.0 GHz**. Then, when the calcium atom has a head – on collision with this light it says that the frequency is:

$$\mathbf{456\ 000.0\ GHz + 0.6\ GHz = 456\ 000.6\ GHz.}$$

continued on the next page . . .

(Turn over)

Question 8 continued**Paragraph 8**

This is the exact frequency for a calcium atom to absorb a photon of our light.

Paragraph 9

So how do we actually do the cooling?

First, we shine light of frequency

456 000.0 GHz at our calcium gas and

remember that only head – on collisions will lead to absorption of photons. Then,

you have to remember that photons have

momentum and absorbing a head – on photon

will slow down the atom which means that the

gas has cooled. The momentum of a photon is

given by the following equation:

EQUATION 4

$$p = \frac{h}{\lambda}$$

continued on the next page . . .

(Turn over)

Question 8 continued

PARAGRAPH 10

So how much does one photon slow down a calcium atom? Conservation of momentum tells us that it's a rather disappointing 1.5 cm s^{-1} .

What?? All that theory and all we did was slow down a calcium atom by 1.5 cm s^{-1} ???

But then you have to think to yourself, "What happens if we can persuade the calcium atom to absorb 26 000 photons?" Fortunately for us, a 50 mW laser tends to send out a lot of photons so that absorbing 26 000 photons only takes about a millisecond.

continued on the next page . . .

Question 8 continued**PARAGRAPH 11**

But what happens if a photon comes from behind and tries to accelerate our atoms? An important thing to remember about this technique is that if the atom is hit from behind by the photon, the atom will see the light as being red – shifted. This means that the frequency has changed the wrong way and the photon will not be absorbed (it no longer fits our exact frequency requirement). So, our atoms will only be slowed down and never accelerated as long as we choose the frequency of light carefully.

continued on the next page . . .

Question 8 continued**Paragraph 12**

Are there any problems that have to be overcome? Of course, there are, otherwise I wouldn't be asking the question:

PARAGRAPH 13

- 1. What happens to the excited atom when it EMITS a photon? Doesn't it gain the momentum it just lost? The answer to that is "No". When atoms emit photons, they do so in random directions. These photons, on average, do not change the rms speed of the gas because the photon has a 50 : 50 chance of being emitted with a velocity component in the direction of motion of the atom or opposite to the direction of motion. However, the recoil of a calcium atom after emitting a photon means that you can't really slow the atoms below around 1.5 cm s^{-1} .**

continued on the next page . . .

(Turn over)

Question 8 continued**Paragraph 14**

2. How do we stop the atoms from hitting the sides of the container? The answer is that we use a magnetic trap ? — it even works on neutral atoms!!

PARAGRAPH 15

3. Does the frequency of the laser have to change as the atoms slow down? Yes, as the atoms slow down, the blue – shift decreases and we have to use frequencies that are closer to **456 000.6 GHz**.

We can actually do this by oscillating our laser mirrors using piezoelectric crystals.

The frequency change of the laser is equal to the frequency of oscillation of the mirrors.

continued on the next page . . .

Question 8 continued**PARAGRAPH 16**

Finally, does this actually work or is it just another thought experiment that works only in Einstein's brain (if he were still alive)?

The answer to that question is

“Yes, since 1978!!!” Furthermore,

temperatures as low as 1 pK may be reachable using the Cold Atom Laboratory which is already on board the International Space Station.

continued on the next page . . .

Question 8 continued

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

- 8. (a) Explain why there is a negative sign in EQUATION 1.**

$$\frac{v}{c} = \frac{\Delta\lambda}{\lambda} = - \frac{\Delta f}{f}$$

[2 marks]

continued on the next page . . .

(Turn over)

Question 8 continued

- 8. (b) (i) Explain why a calcium atom travelling at 400 m s^{-1} will absorb a photon coming directly toward it when the frequency of the photon is $456\,000.0 \text{ GHz}$ (see paragraphs 6 – 8).**

[2 marks]

continued on the next page . . .

(Turn over)

Question 8 (b) continued

8. (b) (ii) Explain why a calcium atom travelling at 400 m s^{-1} will not absorb a **456 000.0 GHz** photon if the photon and atom are moving in the same direction (see paragraphs 6 – 8 and 11).

[1 mark]

8. (b) (iii) Hence, explain very briefly how calcium atoms can be cooled using light of this frequency (see paragraphs 6 – 11).

[1 mark]

continued on the next page . . .

(Turn over)

Question 8 continued

8. (c) Helium has a rms speed of $1\,350\text{ m s}^{-1}$
and an emission line of WAVELENGTH
587.56148 nm.

**Calculate the best laser wavelength
for slowing down helium atoms.**

**Give your answer to 8 significant figures
(see EQUATION 1 and paragraphs 6 – 11).**

[4 marks]

8. (d) Look at the diagram for Question 8 (d) in the separate Diagram Booklet.

The diagram shows a photon being absorbed by a calcium atom.

Show that, when a calcium atom of mass **40 u** absorbs a photon of frequency **4.56×10^{14} Hz**, its velocity decreases by approximately **1.5 cm s^{-1}** .

(Turn over)

[4 marks]

8. (e) The author states that a calcium atom will absorb **26 000** photons in about a millisecond. Discuss whether or not this is possible, given the power of the laser and given that the lifetime of the excited calcium atom is a few nanoseconds. You should reinforce your answer with calculations (see paragraph 10).

(Turn over)

[3 marks]

8. (f) Rhian claims that the random re – emission of photons by excited atoms means that the lowest temperature achievable by this method is approximately $0.1 \mu\text{K}$. Determine whether she is correct (see EQUATION 2 and paragraphs 10 and 13).

(Turn over)

[3 marks]

(Total for Question 8 = 20 marks)

TOTAL FOR SECTION B = 20 MARKS

END OF PAPER

TOTAL 100 MARKS

(Turn over)

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

[illegible]



GCE A LEVEL



A420U10-1

THURSDAY, 26 MAY 2022 – AFTERNOON

PHYSICS – A LEVEL COMPONENT 1

NEWTONIAN PHYSICS

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

Diagram Booklet

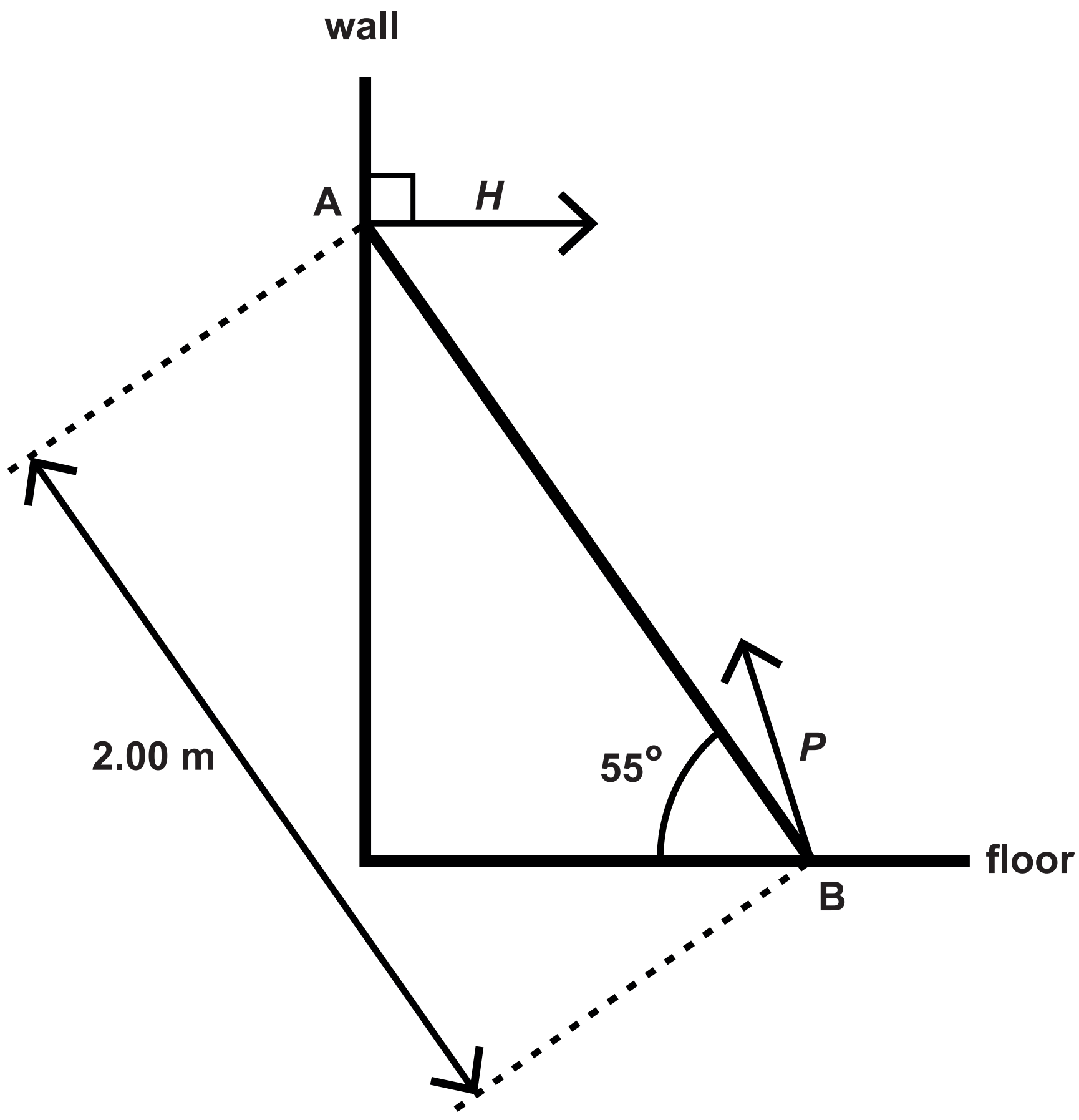
Surname: _____

First name(s): _____

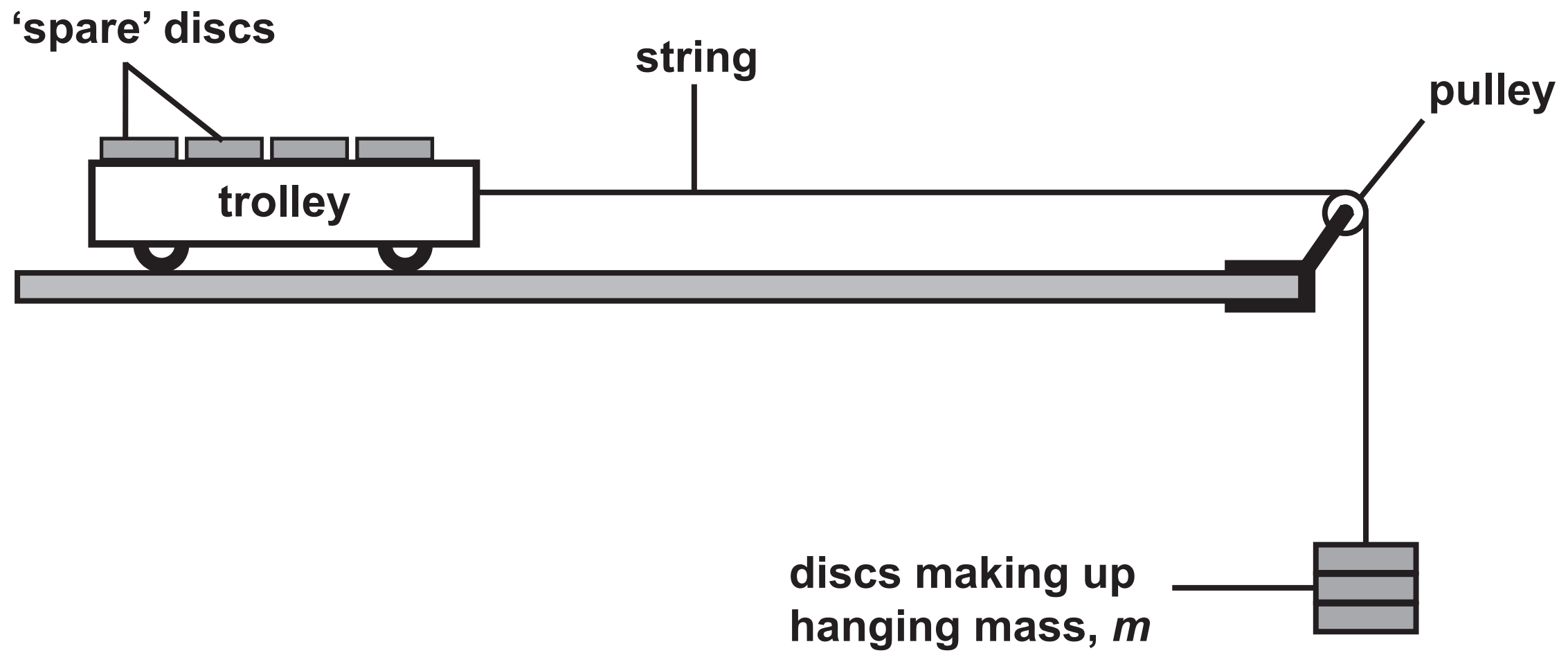
Centre Number: _____

Candidate Number: 2 _____

Question 1

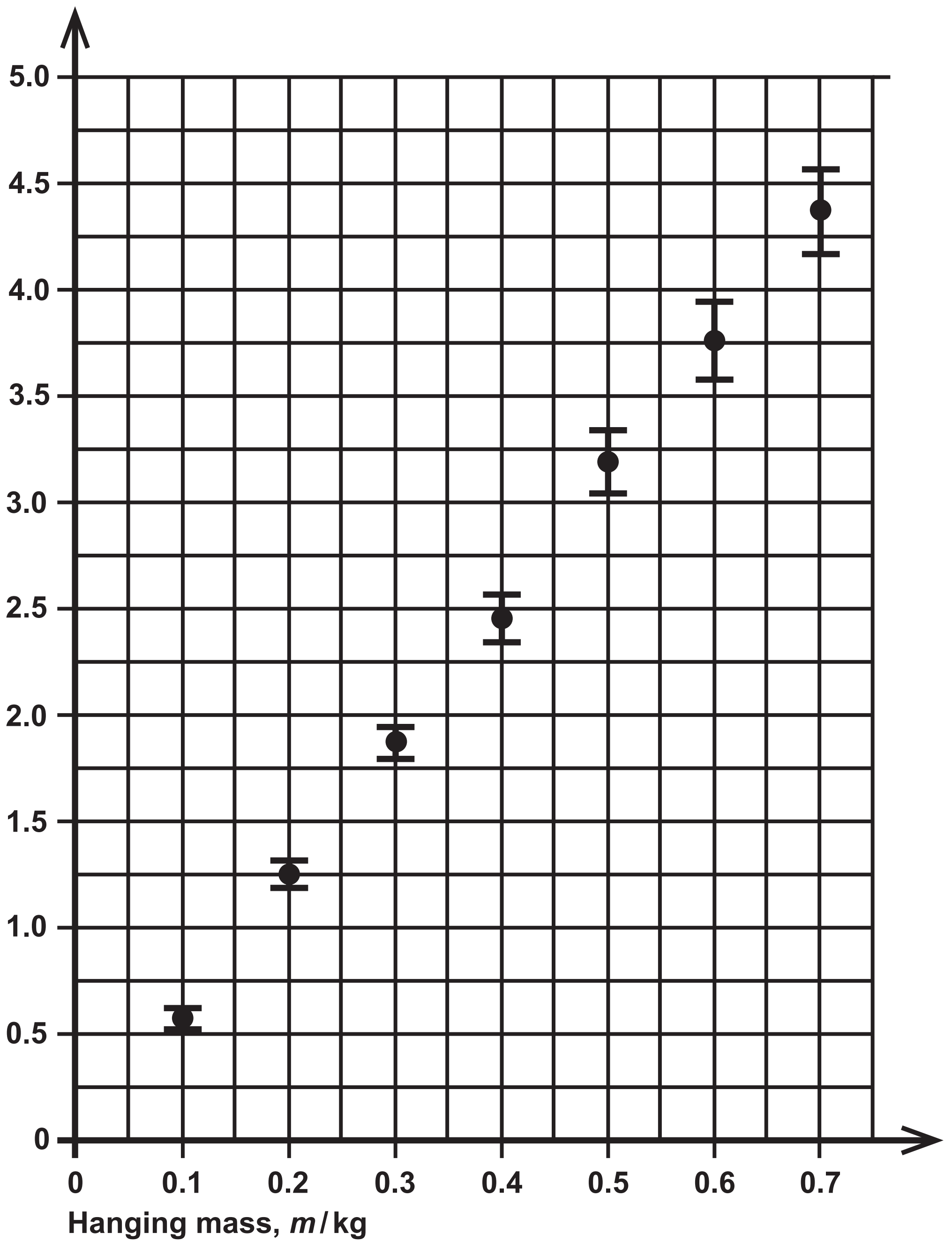


Question 2



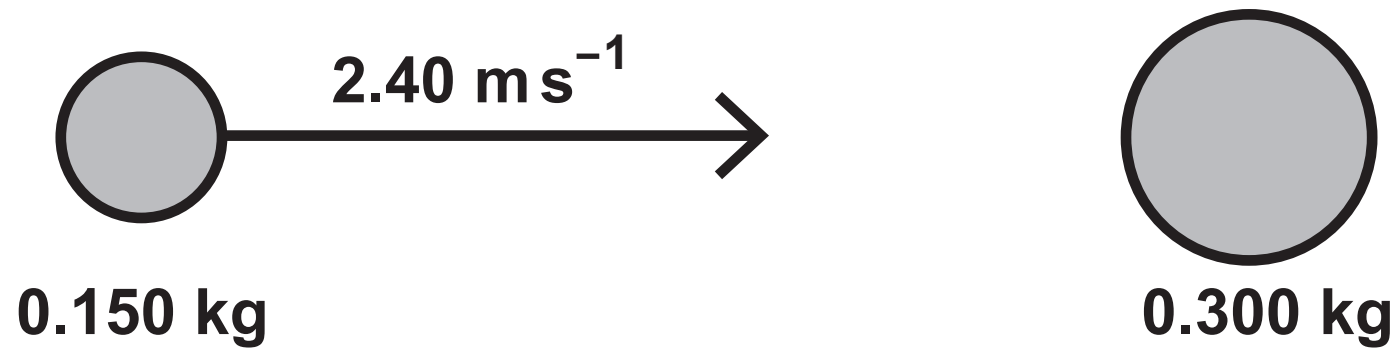
Question 2 (b)

Acceleration / m s^{-2}



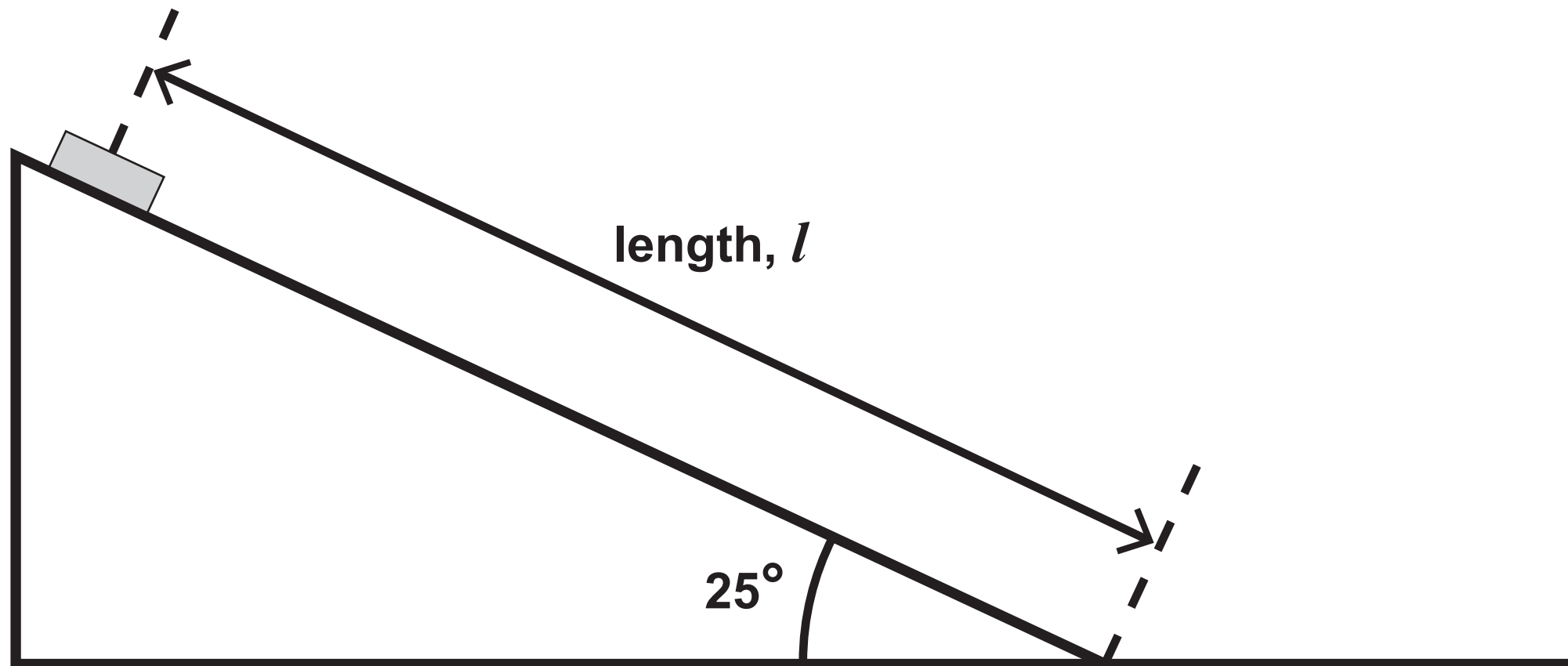
Question 3 (a) (ii)

View from above



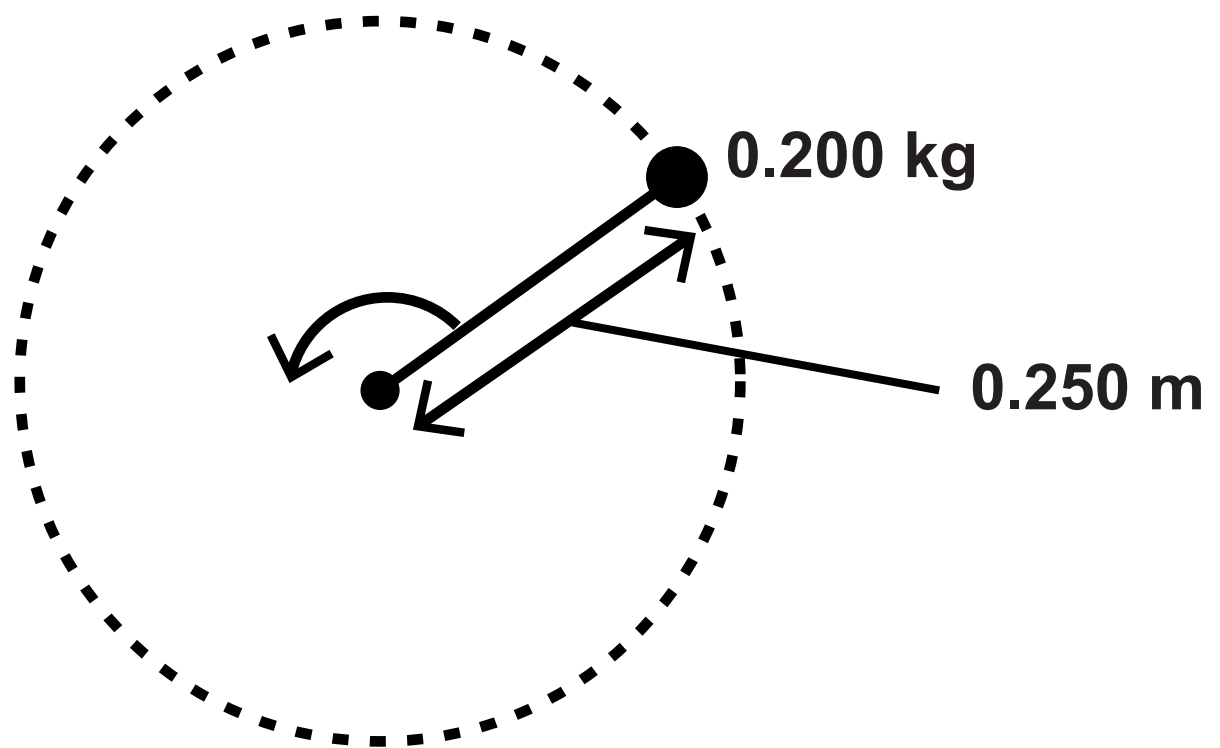
Question 3 (b)

View from side

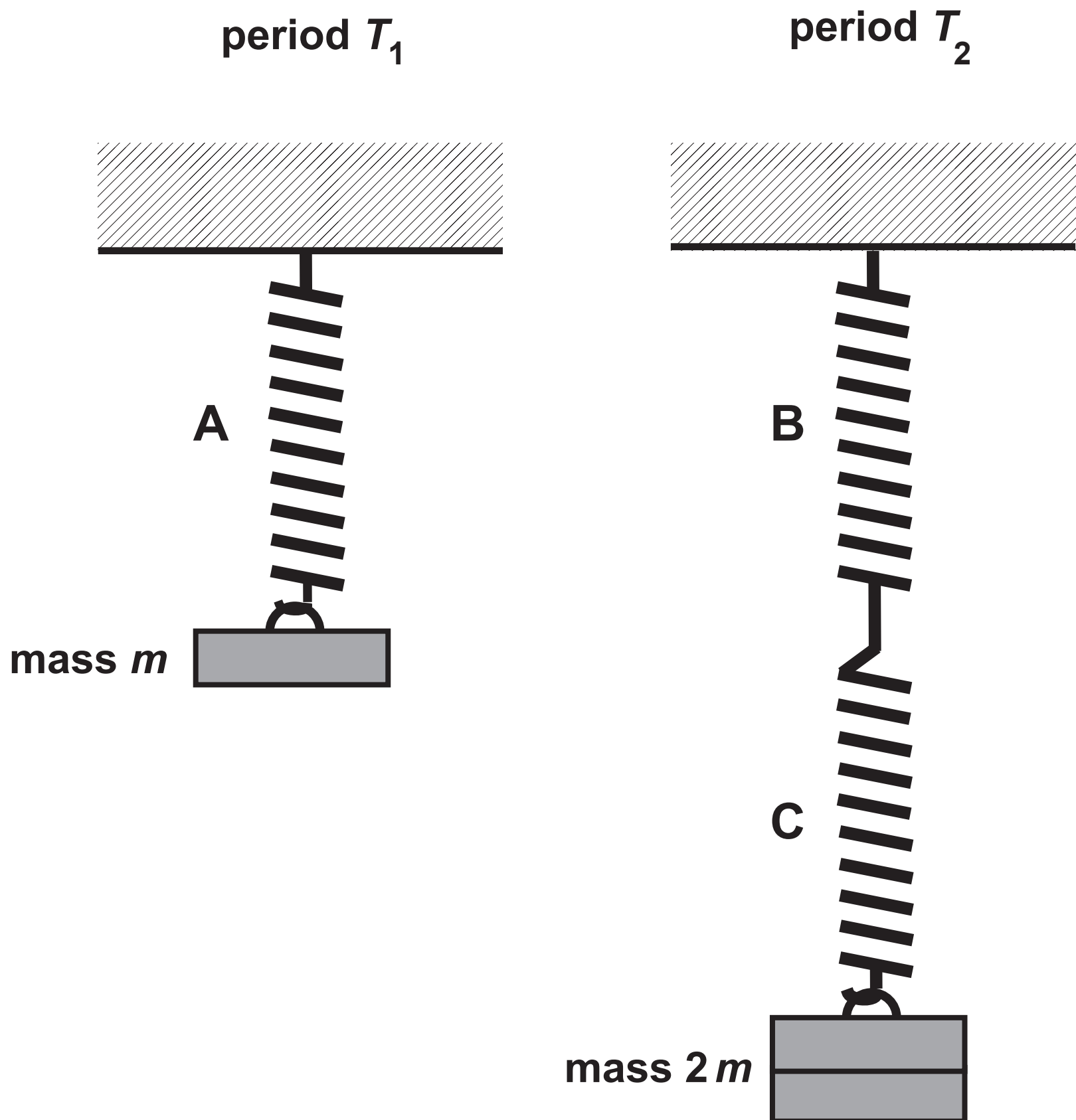


Question 4 (b)

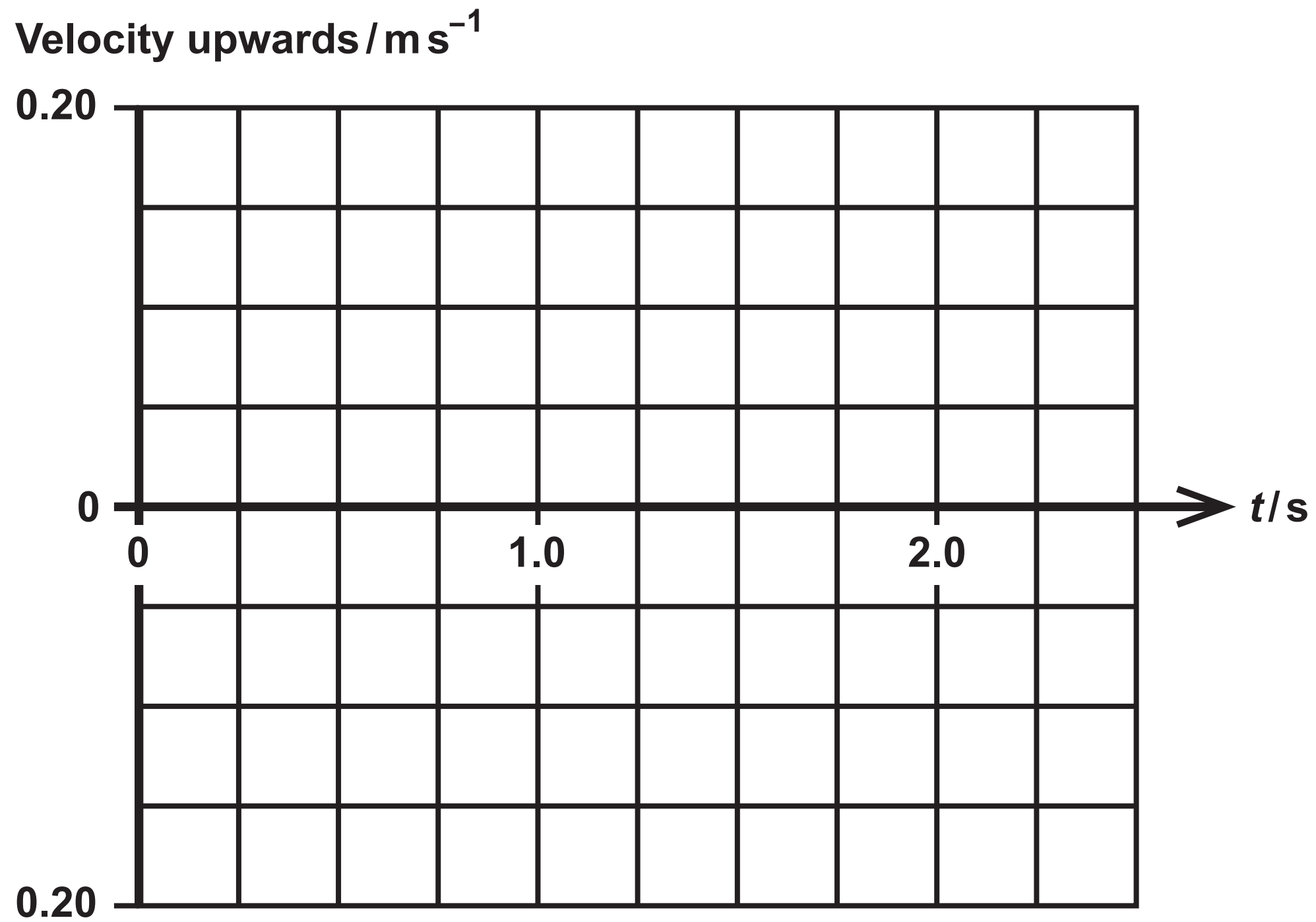
VIEW FROM ABOVE



Question 5 (a)

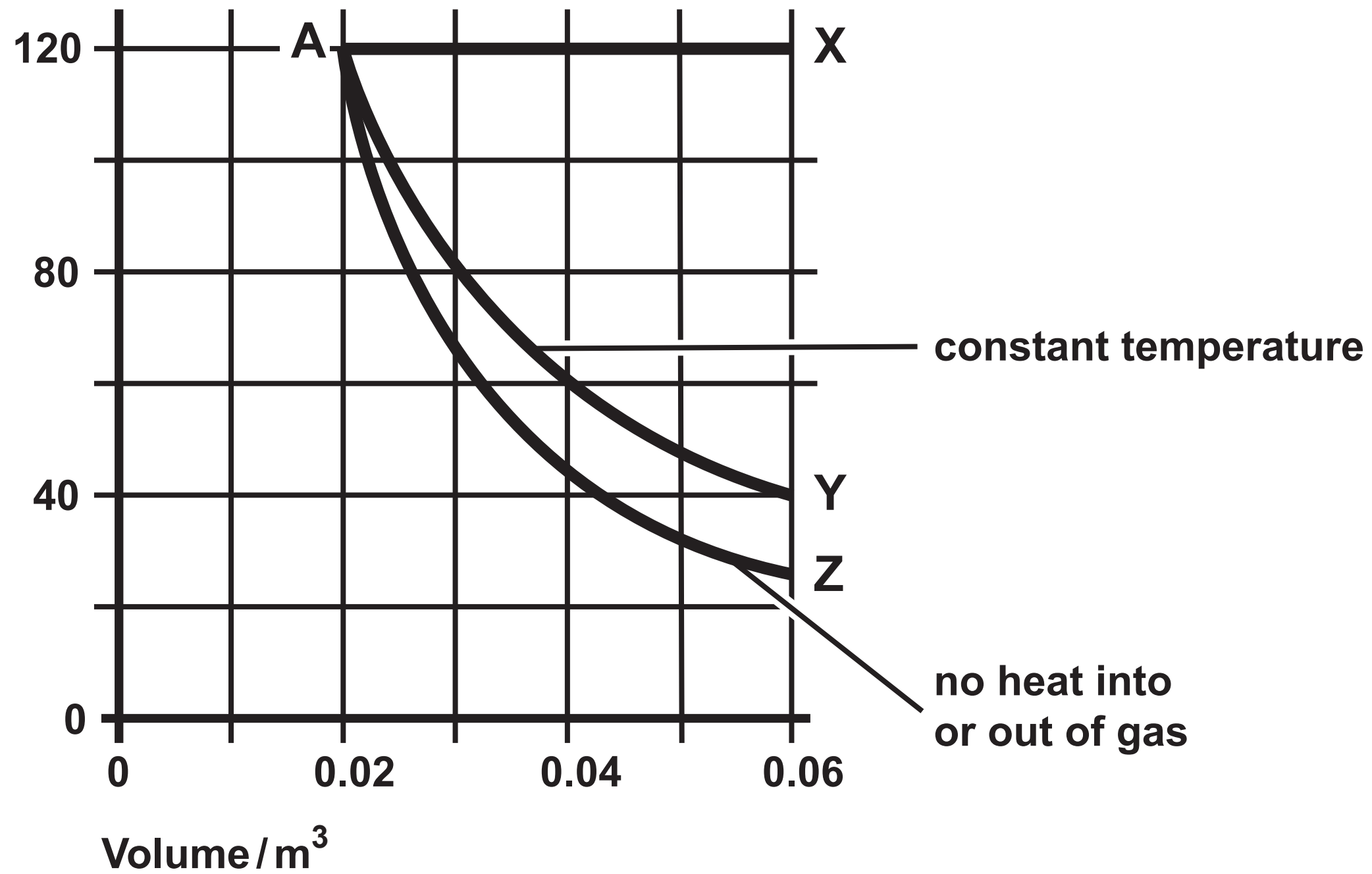


Question 5 (b) (ii)



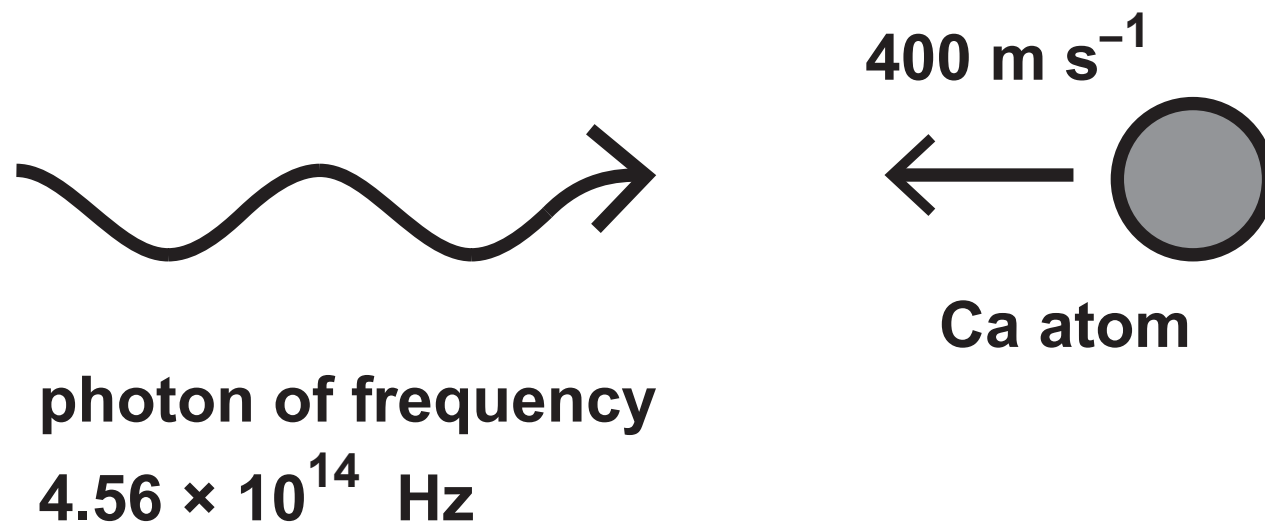
Question 7

Pressure / kPa



Question 8 (d)

Before interaction



After interaction

