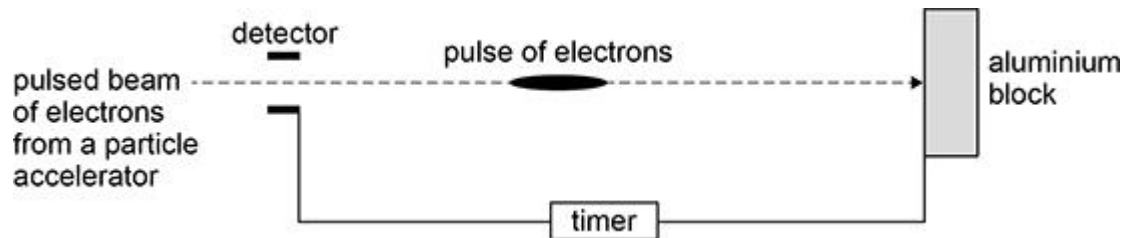


**Q1.**

The figure below shows a modern version of Bertozzi's experiment to measure the kinetic energy of high-speed electrons. A timer is used to measure the time taken for a pulse of electrons to travel from the detector to the aluminium block.



- (a) A potential difference (pd) of 1.30 MV is used to accelerate the electrons.

Show that each electron gains approximately  $2 \times 10^{-13}$  J of kinetic energy.

(1)

- (b) These electrons cause the temperature of the aluminium block to increase by 68.0 K.

The number of electrons that cause this increase in temperature is  $4.50 \times 10^{17}$

Deduce whether this increase in temperature is consistent with an accelerating pd of 1.30 MV.

specific heat capacity of aluminium =  $903 \text{ J kg}^{-1} \text{ K}^{-1}$

mass of aluminium block = 1.50 kg

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(2)

- (c) The speed of the electrons between the detector and the block is  $2.88 \times 10^8 \text{ m s}^{-1}$ .

Student **A** suggests that the non-relativistic equation for kinetic energy could be used.

Student **B** suggests that the relativistic equation for kinetic energy is required in this situation.

Evaluate the suggestions of student **A** and student **B**.  
Support your answer with calculations.

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(4)

- (d) The timer in above figure records a time of 29.8 ns.

What is the proper time interval for an electron travelling from the detector to the aluminium block?

Tick (✓) **one** box.

< 29.8 ns

☐

29.8 ns

☐

> 29.8 ns

☐

(1)

- (e) The electrons in above figure were accelerated from rest in 13 stages.

In each stage the electrons were accelerated by a pd of 100 kV.

As a result, an electron increases its speed and kinetic energy during each stage.

Compare, for an electron,

- its increase in speed for the first stage with that for the last stage
- its increase in kinetic energy for the first stage with that for the last stage.

Justify your answer.

No further calculations are required.

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(4)

(Total 12 marks)

**Q2.**

Einstein developed his theory of special relativity from two postulates. One postulate states that physical laws have the same form in all inertial frames.

- (a) State the other postulate and explain how it is consistent with the equation:

$$c = \sqrt{\frac{1}{\mu_0 \epsilon_0}}$$

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**(2)**

A proton leaves a particle accelerator at point **X** and moves at a constant speed towards a target at point **Y**.

The speed of the proton is  $2.5 \times 10^8 \text{ m s}^{-1}$  in the frame of reference of the target.

The distance **XY** in the frame of reference of the proton is 38 m.

- (b) Calculate the distance **XY** in the frame of reference of the target.

distance **XY** in the frame of reference of the target = \_\_\_\_\_ m

**(2)**

- (c) Show that the kinetic energy  $E_k$  of the proton is about  $1.2 \times 10^{-10}$  J.

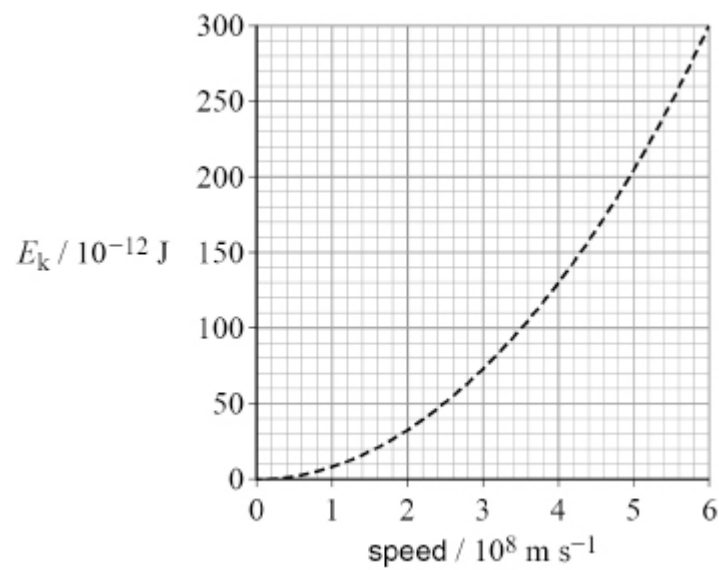
(3)

- (d) Sketch on the figure below the variation of  $E_k$  with speed  $v$  for a proton.

To help you, the dashed line represents

$$E_k = \frac{1}{2} m_0 v^2$$

where  $m_0$  is equal to the mass of a proton at rest.



(3)

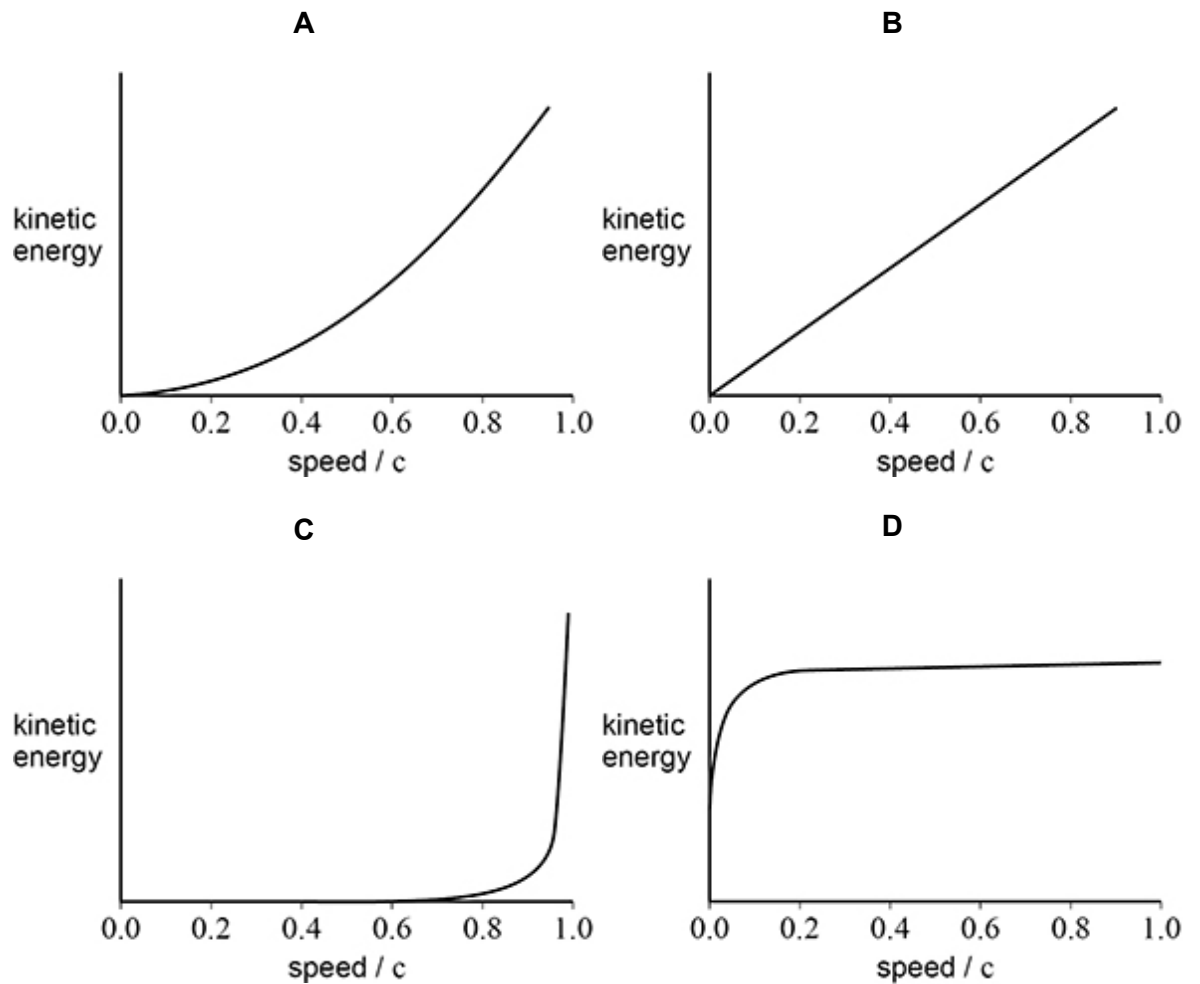
(Total 10 marks)

**Q3.**

- (a) Bertozzi investigated how the kinetic energy of electrons varies with speed.

Which graph shows the variation of kinetic energy with speed?

Tick (✓) **one** box.



**A**

☐

**B**

☐

**C**

☐

**D**

☐

- (b) Calculate the speed of a particle when its kinetic energy is equal to its rest energy.

speed = \_\_\_\_\_  $\text{m s}^{-1}$

(3)

- (c) Discuss the change in the observed mass of a spring when it is stretched.

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(2)

(Total 6 marks)