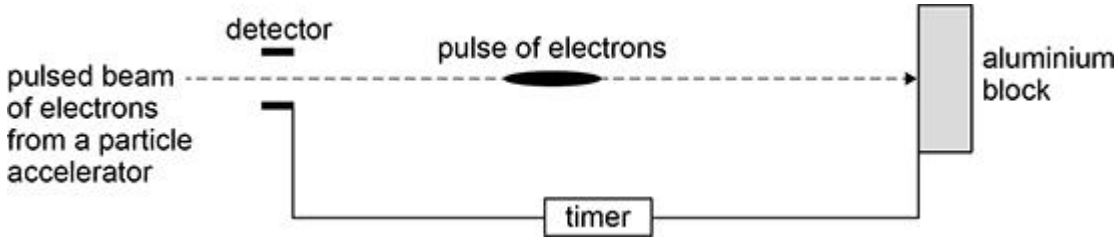
Q1.

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 2×10^{-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 4.50×10^{17}

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

specific heat capacity of aluminium = 903 $\mathrm{J\ kg^{-1}\ K^{-1}}$
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 2.88×10^8 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.

(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:

$$c = \sqrt{\frac{1}{\mu_0 \varepsilon_0}}$$

_____

_____

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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 2.5×10^8 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 1.2×10^{-10} J.

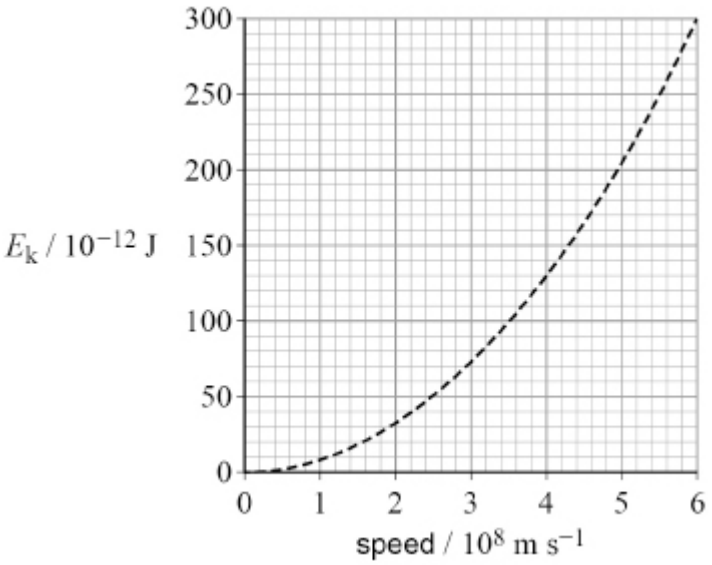
(3)

(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)

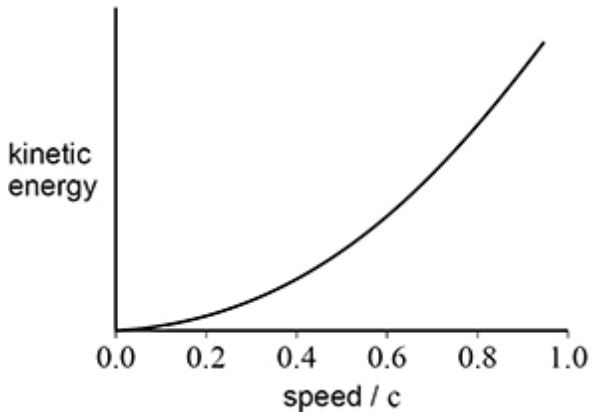
(Total 10 marks)

Q3.

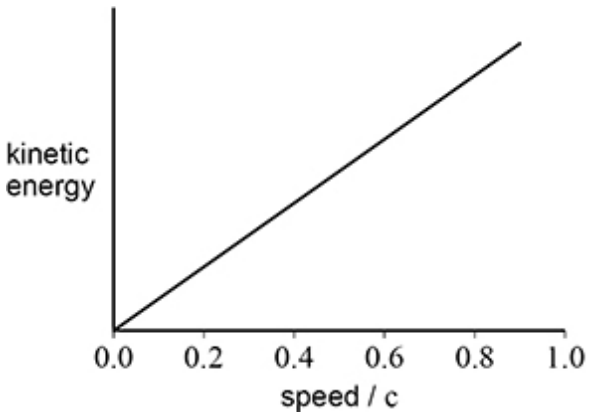
(a) Bertozzi investigated how the kinetic energy of electrons varies with speed.

Which graph shows the variation of kinetic energy with speed?
Tick (✓) **one** box.

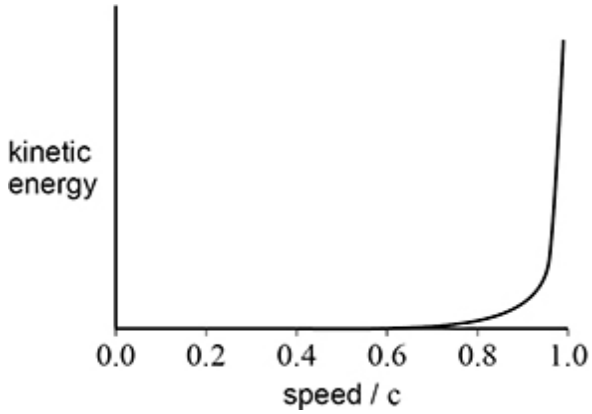
A



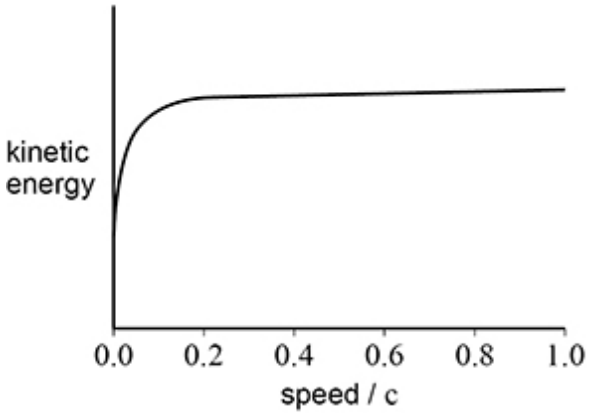
B



C



D



A ☐

B ☐

C ☐

D ☐

(1)

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

speed = _____ 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)