Parts (ii)–(v) concern a particle X, at rest in an inertial frame, which decays into two further particles, Y and Z. Particle Z subsequently decays into radiation. The energy equivalents of the masses of Y and Z are

$$m_Y c^2 = 938\,\text{MeV} \qquad m_Z c^2 = 135\,\text{MeV}$$

where 1 MeV is the unit of energy commonly used in nuclear physics.

Show your working in all the calculations, and express all the results in MeV.

(ii) After the decay of Z, a pulse of radiation of energy 211 MeV is detected in the direction in which Z was travelling before its decay. What is the direction of the *second* pulse of radiation, and what is its energy?

(iii) Calculate the energy of Z, and cp_Z, i.e. its momentum magnitude multiplied by c.

(iv) Calculate the energy of Y.

(v) Calculate $m_X c^2$, the energy equivalent of the mass of X.

$P_Y + P_Z = 0.$

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$E_2 = \frac{m_2 c^2}{\sqrt{1-v^2/c^2}}$ $\qquad E = E_1 + E_2$

P

$2E_1E_2(1-\cos\theta) = m^2c^4$

$2 \times 211 \times E_2 \times 2 = (135)^2$

$E_2 = \frac{(135)^2}{844}$ MeV.

ii) $E_2 = E_1 + E_2 = \left(211 + \frac{(135)^2}{844}\right)$ MeV.

iii) $P = \frac{E_1}{c} + \frac{E_2}{c}\left(\frac{(135)^2}{844} + 211\right)/3E8 = 7.753E-7$

iv) $cp_Z = 232.59$ MeV.

iv) $cp_Z = cp_Y$ $\qquad cp_y = 232.59$

$\cancel{\frac{m_2 v}{\sqrt{1-v^2/c^2}} = \frac{m_y v}{\sqrt{1-v^2/c^2}} = 232.59}$ $\qquad \frac{mvc}{\sqrt{1-v^2/c^2}} = 232.59$

$\cancel{\frac{m_y c^2 v}{\sqrt{1-v^2/c^2}} = 232.59}$ $\qquad \frac{938v}{\sqrt{1-v^2/c^2}}$ $\qquad \frac{mvc^2}{\sqrt{1-v^2/c^2}} = 232.59c$

$\frac{mcv}{\sqrt{1-v^2/c^2}} = 232.59$ $\qquad \frac{v}{\sqrt{1-v^2/c^2}} = \frac{232.59c}{938}$

$\frac{938v/c}{\sqrt{1-v^2/c^2}} = 232.59$ $\qquad \frac{v^2}{1-v^2/c^2} =$

$\frac{v^2/c^2}{1-v^2/c^2} = 0.06149$ $\qquad v^2/c^2 = 0.06149 - 0.06149v^2/c^2$

$v = 0.1979c.$