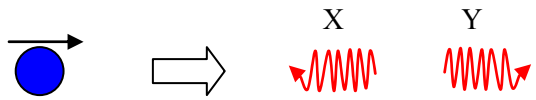
Extension Worksheet – Option H, Worksheet 3

1 A neutral pion (of rest mass 135 MeV c^{-2}) moving at 0.80 c relative to a laboratory decays into two photons, X and Y. One photon is emitted in the direction of motion of the pion and the other in the opposite direction.



Calculate, relative to the laboratory,

a the momentum of the pion. [2]

b the total energy of the pion. [1]

c the energy of each of the photons. [4]

2 Theoretically, two particles each of rest mass 600 MeV c^{-2} moving in opposite directions each with speed 0.80 c relative to a laboratory may collide and join to form a single particle.

a Calculate the total energy of one of the particles relative to the laboratory. [2]

b Determine the total kinetic energy of the two particles. [2]

c Deduce that the rest mass of the single particle formed in the collision is 2000 MeV c^{-2}. [1]

d Discuss the law of conservation of mass in this collision. [2]

3 Use the equivalence principle to predict that a ray of light bends towards a massive body. [3]

4 Use the equivalence principle to predict that the frequency of a ray of light decreases as the ray moves away from a massive body. [3]

5 A probe is placed at a distance of $2.00R_S$ from the centre of a black hole, where R_S is the Schwarzschild radius of the hole. The probe emits a pulse of light of frequency 5.00×10^{14} Hz. The duration of the pulse is 2.00 μs according to a clock in the probe. The light is received by a spacecraft very far away from the hole. Calculate

a the number of full waves emitted by the probe. [2]

b the duration of the pulse according to the clocks in the spacecraft. [2]

c the frequency of the light received by the spacecraft. [2]

6 A clock is placed near a black hole. The time interval between two events according to this clock is 5.0 s. The time interval between the same two events according to a clock very far from the black hole is 10 s. Calculate the distance of the first clock from the centre of the black hole in terms of the Schwarzschild radius of the hole. [3]