State Examination Commission – Physics Higher Level, 2008

Question 10 a

Baryons and mesons are made up of quarks and experience the four fundamental forces of nature.
List the four fundamental forces and state the range of each one. (8)
Name the three positively charged quarks.
What is the difference in the quark composition of a baryon and a meson?
What is the quark composition of the proton? (12)
In a circular accelerator, two protons, each with a kinetic energy of 1 GeV, travelling in opposite directions, collide. After the collision two protons and three pions are emitted.
What is the net charge of the three pions? Justify your answer. (9)
Calculate:
(i) the combined kinetic energy of the particles after the collision;
(ii) the maximum number of pions that could have been created during the collision. (24)
(charge on electron = 1.6022×10^{-19} C; mass of proton = 1.6726×10^{-27} kg; mass of pion = 2.4842×10^{-28} kg; speed of light = 2.9979×10^{8} m s^{-1})

List the four fundamental forces and state the range of each one. (8)

Force	Gravity	Electromagnetism	Strong	Weak
Range	∞	∞	10^{-15} m	10^{-18} m

Name the three positively charged quarks.

Up, charmed and top

What is the difference in the quark composition of a baryon and a meson?

Baryons are mad of three quarks or anti-quarks. Mesons are made of one quark and one anti-quark.

What is the quark composition of the proton? (12)

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In a circular accelerator, two protons, each with a kinetic energy of 1 GeV, travelling in opposite directions, collide. After the collision two protons and three pions are emitted.What is the net charge of the three pions? Justify your answer.

The net charge is zero as otherwise the principle of conservation of charge would be violated.

Calculate:
(i) the combined kinetic energy, E_k , of the particles after the collision;

Total mass-energy before collision $E = 2(1.6726 \times 10^{-27})(2.9979 \times 10^{8})^2 + 2(1 \times 10^{9} \times 1.6022 \times 10^{-19})$
$= 6.2109 \times 10^{-10}$ J
= Total mass-energy after collision
$6.2109 \times 10^{-10} = 2(1.6726 \times 10^{-27})(2.9979 \times 10^{8})^2 + 3(2.4842 \times 10^{-28})(2.9979 \times 10^{8})^2 + E_k$
$E_k = 2.535 \times 10^{-10}$ J

(ii) the maximum number of pions that could have been created during the collision.

2.535×10^{-10} J of energy is equivalent to $2.535 \times 10^{-10} / (2.9979 \times 10^{8})^2$ of mass
i.e. 2.8206×10^{-27} kg of mass.
Now, $2.8206 \times 10^{-27} / 2.4842 \times 10^{-28} = 11.4$
=> up to an additional 11 more pions could have been created, giving a total of 14 pions.