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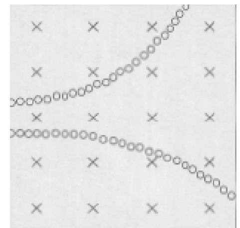
Practice problems

1) Neutrinos are difficult to detect because (a) they are neutral and do not form bubbles or vapour trails in bubble or cloud chambers. In addition, they generally do not interact with other forms of matter.



2) Using the hand rules for particles entering a magnetic field, the top particle is positive and the bottom particle is negative.

To determine which particle is moving faster we look at the relationship between radius, speed, mass and charge.

$$F_c = F_m$$
$$\frac{mv^2}{r} = qvB_\perp$$
$$r = \frac{mv}{qB_\perp}$$

The radius depends directly on the mass and speed, and inversely on the charge. Therefore, a particle may, for example, appear to be going fast, but it may merely be less massive.

3)
- (a) The particle tracks appear in the middle of the diagram without an apparent cause. Since no tracks are visible for the initial particle it is likely that it was a photon.
- (b) The photon was moving horizontally and entered the chamber from the left.
- (c) Using the appropriate hand rule, the bottom particle is positive.
- (d) (1) Using the appropriate hand rule, the other particle is negative. (2) A photon is neutral. In order to conserve charge if a positive particle is produced a negative particle must also be produced.
- (e) Each particle has the same mass but opposite charge.
- (f) Since each particle has the same mass but opposite charge, it is most likely that they will be a particle-antiparticle pair.

4)
$$E = \Delta mc^2$$
$$E = (1.674927\times10^{-27}\,kg)(3.00\times10^{8}\,\tfrac{m}{s})^2$$
$$\boxed{E = 1.5074343\times10^{-10}\,J}$$
$$E = \frac{1.5074343\times10^{-10}\,J}{1.60\times10^{-19}\,\frac{J}{eV}}$$
$$\boxed{E = 942.1464\,MeV}$$

Hand-in assignment

1) In a cloud chamber, charged particles interact with a vapour which causes the vapour to condense into small droplets which we can see. In a bubble chamber, a liquid is held just below its boiling point. When a charged particle goes through the liquid it causes the liquid to boil which creates tiny gas bubbles which we can then see. Only charged and ionizing photons may be seen in cloud or bubble chambers.

/4 Advantages of a bubble chamber: It is easier to produce an environment and sustain a trail with a liquid in a bubble chamber than one with a supercooled gas in a cloud chamber. In addition, if liquid hydrogen is used, the protons in the hydrogen nucleus act as collision targets.

2) Electrons, protons, alpha particles, and any subatomic particles with a charge will leave tracks in a bubble chamber. Neutrons, photons, and any particles with no charge will not leave tracks in a bubble chamber.

/2

3) When charged particles travel perpendicular to an external magnetic field, they experience a deflecting force that causes them to travel in a curved path.

/2 The direction of deflection can reveal the charge on the particle, and the radius of the deflection can determine the mass or amount of charge on the particle.

4)

(a) Since the alpha particle is much heavier than the proton, it will deflect in an arc with a larger radius.

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(b) Since the electron has a negative charge and the proton has a positive charge, they will deflect in different directions if they pass through a magnetic field. The proton is more massive than the electron, so its radius of arc will be larger.

5) The strongest fundamental force over large distances is the electromagnetic force for electrically charged objects and the gravitational force for very massive objects. The weakest fundamental force at nuclear distances is the gravitational force since the masses are so small.

/2

6) Quantum field theory involves the exchange of virtual particles that mediate the interactions between particles.

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7) The event $e^- + e^+ \longrightarrow 2\gamma$ is an electron/positron annihilation.

/2 The event $e^- + e^+ \longrightarrow \gamma$ is not possible since momentum would not be conserved. Two gamma rays moving in opposite directions are required to conserve linear momentum.

8) Two protons will attract each other in a strong force interaction when they are approximately 1 to 2.5 fm apart from each other.

/2 The protons will repel each other via the electromagnetic interaction when they are more than 2.5 fm apart.

9) Alpha particles are quite large when compared to a nucleus, but they are quite small when compared to an atom with its electrons circling a nucleus.

/2 Therefore, they can be use to probe atomic structure but they cannot be used to probe nuclear structure.

10)

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(a) The clockwise bend (palm) in the path of the proton (right hand rule) suggests that the magnetic field must be oriented out of the page (fingers).

(b) The kinetic energy of the original proton will be shared between the scattered proton and the hydrogen atom's nucleus (proton) which implies that they will travel at a slower speed than the original proton. From the clockwise bend in all of the paths, the particles are all positive.

(c) The small spiral tracks are probably due to electrons. They must be negative since their direction of deflection is opposite that of the protons. The spiral is due to the electrons slowing down.

11)

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(a) Using the right-hand rule, the particle has a positive charge.

(b) The initial radius of the particle's path is approximately 10 cm.

(c) From the equation

$$F_c = F_m$$

$$\frac{mv^2}{r} = qvB_\perp$$

$$mv = qB_\perp r \qquad (p = mv)$$

$$p = qB_\perp r$$

$$p = q(1.2T)(0.10m)$$

$$p = 0.12q$$

If you know the charge, then you can determine an actual value for the magnitude of the momentum.

(d) The inward spiral suggests that the particle is losing energy, and hence momentum.

(e) The short tracks are likely secondary, weak collisions between the positive charge and other hydrogen nuclei in the bubble chamber.

12)

$$E = mc^2$$

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$$m_\psi = \frac{E_\psi}{c^2}$$

$$m_\psi = \frac{3.097\times10^{9}\,eV(1.60\times10^{-19}\ \tfrac{J}{eV})}{(3.00\times10^{8}\ {}^{m}\!/\!{}_{s})^2}$$

$$\boxed{m_\psi = 5.51\times10^{-27}\,kg}$$

13) The nuclear equation is

$${}^{32}_{15}P \;\rightarrow\; {}^{32}_{16}S \;+\; {}^{0}_{-1}e \;+\; \bar{\nu} \;+\; (E_{ke^-} + E_{k\bar{\nu}})$$

Let us solve the problem using the principle of mass-energy conservation.

$$E_{{}^{32}_{15}P} = m_{{}^{32}_{15}P}c^2$$

$$E_{{}^{32}_{15}P} = (31.97390u\times1.660540\times10^{-27}\ \tfrac{kg}{u})c^2$$

$$E_{{}^{32}_{15}P} = 4.7784546\times10^{-9}\,J$$

$$E_{{}^{0}_{-1}e} = m_{{}^{0}_{-1}e}c^2$$

$$E_{{}^{0}_{-1}e} = (5.485799\times10^{-4}\,u\times1.660540\times10^{-27}\ \tfrac{kg}{u})c^2$$

$$E_{{}^{0}_{-1}e} = 8.198450\times10^{-14}\,J$$

$$E_{{}^{32}_{15}P} = E_{{}^{32}_{16}S} + E_{{}^{0}_{-1}e} + E_{\bar{\nu}} + E_{ke^-} + E_{k\bar{\nu}}$$

$$E_{{}^{32}_{16}S} = m_{{}^{32}_{16}S}c^2$$

$$E_{{}^{32}_{16}S} = (31.97207u\times1.660540\times10^{-27}\ \tfrac{kg}{u})c^2$$

$$E_{{}^{32}_{16}S} = 4.77818110\times10^{-9}\,J$$

$$E_{ke^-} = 0.90\times10^{6}\,eV\times1.60\times10^{-19}\ \tfrac{J}{eV}$$

$$E_{ke^-} = 1.44\times10^{-13}\,J$$

$$E_{\bar{\nu}} = 0 \text{ (massless!!)}$$

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$$E_{{}^{32}_{15}P} = E_{{}^{32}_{16}S} + E_{{}^{0}_{-1}e} + E_{\bar{\nu}} + E_{ke^-} + E_{k\bar{\nu}}$$

$$E_{k\bar{\nu}} = E_{{}^{32}_{15}P} - (E_{{}^{32}_{16}S} + E_{{}^{0}_{-1}e} + E_{\bar{\nu}} + E_{ke^-})$$

$$E_{k\bar{\nu}} = 4.7784546\times10^{-9}\,J - (4.77818110\times10^{-9}\,J + 8.198450\times10^{-14}\,J + 0 + 1.44\times10^{-13}\,J)$$

$$E_{k\bar{\nu}} = 4.75155\times10^{-14}\,J$$

$$\boxed{E_{k\bar{\nu}} = 0.297MeV}$$

14) The kinetic energy of the electron will be a maximum if the electron antineutrino has an energy of zero:

$${}^{12}_{5}B \;\rightarrow\; {}^{12}_{6}C \;+\; {}^{0}_{-1}e \;+\; \bar{\nu} \;+\; E_{ke^-}$$

$\Delta m = \Sigma\, m_{products} - \Sigma\, m_{reactants}$
$\Delta m = (12.00000\ u + 5.485799 \times 10^{-4} u) - (12.01435\ u)$
$\Delta m = -0.01380142\ u$
$\Delta m = -0.01380142\ u\ \ x\ \ 1.660540 \times 10^{-27}\ kg/u\ = -2.29178 \times 10^{-29}\ kg$

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$E_{ke} = \Delta m\, c^2 = (2.29178 \times 10^{-29}\ kg)(3.00 \times 10^{8}\ m/s)^2 = 2.062603 \times 10^{-12}\ J$
$E_{ke} =$ **12.89127 MeV**

15) The nuclear equation is

$$^{12}_{7}\mathrm{N} \rightarrow {}^{12}_{6}\mathrm{C} + {}^{0}_{+1}\mathrm{e} + \nu + (E_{ke^+} + E_{k\nu})$$

Let us solve the problem using the principle of mass-energy conservation.

$$E_{^{12}_{7}N} = m_{^{12}_{7}N}c^2$$

$$E_{^{12}_{7}N} = (12.01864\mathrm{u} \times 1.660540 \times 10^{-27}\,\tfrac{\mathrm{kg}}{\mathrm{u}})c^2$$

$$E_{^{12}_{7}N} = 1.7961689 \times 10^{-9}\,\mathrm{J}$$

$$E_{^{0}_{+1}e} = m_{^{0}_{-1}e}c^2$$

$$E_{^{0}_{+1}e} = (4.485799 \times 10^{-4}\,\mathrm{u} \times 1.660540 \times 10^{-27}\,\tfrac{\mathrm{kg}}{\mathrm{u}})c^2$$

$$E_{^{0}_{+1}e} = 6.7039638 \times 10^{-14}\,\mathrm{J}$$

$$E_{^{12}_{7}N} = E_{^{12}_{6}C} + E_{^{0}_{+1}e} + E_{\nu} + E_{ke^+} + E_{k\nu}$$

$$E_{^{12}_{6}C} = m_{^{12}_{6}C}c^2$$

$$E_{^{12}_{6}C} = (12.00000\mathrm{u} \times 1.660540 \times 10^{-27}\,\tfrac{\mathrm{kg}}{\mathrm{u}})c^2$$

$$E_{^{12}_{6}C} = 1.7933832 \times 10^{-9}\,\mathrm{J}$$

$$E_{k\nu} = 11.0 \times 10^{6}\,\mathrm{eV} \times 1.60 \times 10^{-19}\,\tfrac{\mathrm{J}}{\mathrm{eV}}$$

$$E_{k\nu} = 1.76 \times 10^{-12}\,\mathrm{J}$$

$$E_{\bar{\nu}} = 0 \text{ (massless!!)}$$

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$$E_{^{12}_{7}N} = E_{^{12}_{6}C} + E_{^{0}_{+1}e} + E_{\nu} + E_{ke^+} + E_{k\nu}$$

$$E_{ke^+} = E_{^{12}_{7}N} - (E_{^{12}_{6}C} + E_{^{0}_{+1}e} + E_{\nu} + E_{k\nu})$$

$$E_{k\bar{\nu}} = 1.7961689 \times 10^{-9}\,\mathrm{J} - (1.7933832 \times 10^{-9}\,\mathrm{J} + 6.7039638 \times 10^{-14}\,\mathrm{J} + 0 + 1.76 \times 10^{-12}\,\mathrm{J})$$

$$E_{k\bar{\nu}} = 9.586604 \times 10^{-13}\,\mathrm{J}$$

$$\boxed{E_{k\bar{\nu}} = 5.99\,\mathrm{MeV}}$$

16)

$$n_{accelerations} = \frac{\text{final energy}}{\text{energy per acceleration}}$$

/3

$$n_{accelerations} = \frac{25000\,\mathrm{keV}}{30\,\mathrm{keV}}$$

$$n_{accelerations} = 833$$

Since there are two accelerations per revolution

$$n_{revolutions} = \frac{n_{accelerations}}{2}$$

$$n_{revolutions} = \frac{833}{2}$$

$$\boxed{n_{revolutions} = 417}$$

17)

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$$E_{total} = E_{initial} + n_{rev}E_{rev}$$

$$n_{rev} = \frac{E_{total} - E_{initial}}{E_{rev}}$$

$$n_{rev} = \frac{1.0 \times 10^{12}\,\mathrm{eV} - 8.0 \times 10^{9}\,\mathrm{eV}}{3.0 \times 10^{6}\,\mathrm{eV}}$$

$$\boxed{n_{rev} = 3.3 \times 10^{5}\,\mathrm{rev}}$$

$$d = n \times C$$

$$d = 3.3 \times 10^{5}\,\mathrm{rev} \times 6.4\,\mathrm{km}/\mathrm{rev}$$

$$\boxed{d = 2.1 \times 10^{9}\,\mathrm{m}}$$

18) $E = mc^2$

/3 $E = 2m_n c^2$

$E = 2(1.674927\times10^{-27}\,\text{kg})(3.00\times10^{8}\,\text{m/s})^2$

$E = 3.01487\times10^{-10}\,\text{J}$

$\boxed{E = 1.88\,\text{GeV}}$

19) $E = mc^2$

/5 $E = 2m_e c^2$

$E = 2(9.109383\times10^{-31}\,\text{kg})(3.00\times10^{8}\,\text{m/s})^2$

$E = 1.6397\times10^{-13}\,\text{J}$

$E = hf$

$E = (6.63\times10^{-34}\,\text{J}\cdot\text{s})(1.8\times10^{18}\,\text{Hz})$

$E = 1.19\times10^{-15}\,\text{J}$

Pair production will not take place. The required energy is 1.6397 x 10^{-13} J, while the photon has a mere 1.19 x 10^{-15} J of energy.

20) $e^- + e^+ \longrightarrow 2\gamma$

$E = mc^2$

$E = 2m_e c^2$

/5 $E = 2(9.109383\times10^{-31}\,\text{kg})(3.00\times10^{8}\,\text{m/s})^2$

$E = 1.6397\times10^{-13}\,\text{J}$

$\frac{E}{2} = \frac{hc}{\lambda}$

$\lambda = \frac{2hc}{E}$

$\lambda = \frac{2(6.63\times10^{-34}\,\text{J}\cdot\text{s})(3.00\times10^{8}\,\text{m/s})}{(1.6397\times10^{-13}\,\text{J})}$

$\boxed{\lambda = 2.43\times10^{-12}\,\text{m}}$

