Q1. $t = \frac{5.00s}{\sqrt{1-0.7^2}} = 7.00s$

Q2. $E = \gamma m_p c^2 \Rightarrow 1.875 \times 10^9 = \gamma\,(938.272 \times 10^6)$

$$\gamma = 1.998$$

$$\gamma = \frac{1}{\sqrt{1-\beta^2}} \Rightarrow \beta = 0.866c = 2.597 \times 10^8 m/s$$

Q3. $E = \Delta mc^2$

$$= (235.043924 + 1.008665 - 139.921620 - 93.915367 - 2 \times 1.008665\,)\mathrm{u} \times 931.494 \frac{\mathrm{MeV}}{\mathrm{c}^2}$$
$$= 0.198272 \times 931.494 \text{ MeV} = 184.69 \text{ MeV}$$

Q4. D

Q5. Photoelectric Effect; Compton Shift; Pair Production.

Q6. Counts from source at 80 cm (at t=0) = 78-10= 68 s^{-1}.

Counts from source at 80 cm (at t=30 min) = $\left(\frac{1}{2}\right)^{3/2} \times 68 = 24\ s^{-1}$.

Counts from source at 40 cm (at t=30 min) = $24 \times 2^2 = 96\ s^{-1}$; 106 s^{-1} (including background)

Q7. $\Delta\lambda = \frac{h}{mc}(1-\cos\theta) = \frac{6.6\times10^{-34}}{9.11\times10^{-31}\times3\times10^8}(1-\cos 60°) = 1.21 \times 10^{-12} m$

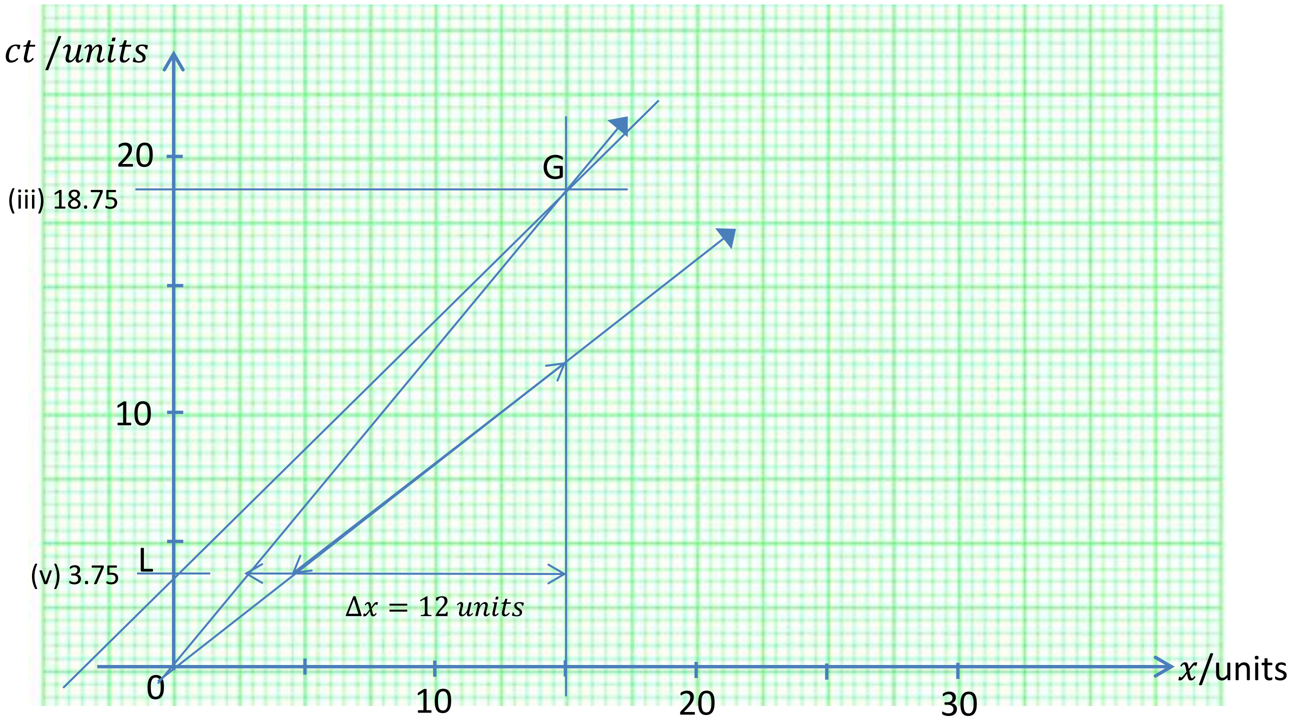
Q8. $|3,0,0\rangle, |3,1,0\rangle, |3,1,-1\rangle, |3,1,1\rangle, |3,2,0\rangle, |3,2,-1\rangle, |3,2,1\rangle, |3,2,-2\rangle, |3,2,2\rangle; -\frac{13.6}{3^2} = -1.51\ eV$

Q9. $\lambda \geq d$

$$\frac{h}{p} \geq n^{-\frac{1}{3}}$$
$$\left(\frac{h}{p}\right)^2 \geq n^{-\frac{2}{3}}$$
$$\frac{h^2 n^{\frac{2}{3}}}{2m} \geq \frac{p^2}{2m} = k_b T$$
$$T \leq \frac{h^2 n^{\frac{2}{3}}}{2mk_b}$$

Sect B

Q1.



Space Station S Frame

i) vertical line at $x = 15$ *units*

ii) as shown, $\beta = 0.8, \gamma = 1\frac{2}{3}$.

iii) $ct = \frac{15}{0.8} = 18.75$ *units*

iv) $ct' = \gamma(ct - \beta x) => ct'_O = \frac{5}{3}\left(18\frac{3}{4} - \frac{4}{5} \times 15\right) = 11.25$ *units*

v) $ct_1 = 18.75 - 15 = 3.75$ *units*

vi) At $ct = 3.75$, distance of space shuttle to shield = 15-0.8*3.75=12 units measured in space station frame.

$$\Delta x = \gamma(\Delta x' - \beta c \Delta t') => 12 = \frac{5}{3}(\Delta x' - 0.8 \times 0) => \Delta x' = 7.2 \text{ units}$$

Q2a)

$$n = 3 \rightarrow n = 2, longest\ visible$$
$$n = 6 \rightarrow n = 2, shortest\ visible$$

$$\Delta E = -E_o\left(\frac{1}{3^2} - \frac{1}{2^2}\right) => \lambda = 656.3nm => 19.16°$$

$$d \sin\theta = \lambda$$

$$\Delta E = -E_o\left(\frac{1}{6^2} - \frac{1}{2^2}\right) => \lambda = 410.2nm => 11.84°$$

b)

i.

$$\frac{p^2}{2m} = e\Delta V$$
$$\frac{\left(\frac{h}{\lambda}\right)^2}{2m} = e\Delta V => \lambda = 1.73 \times 10^{-11}m$$

ii.

$$E = K + mc^2 = (200 \times 10^3 + 511 \times 10^3)\ eV = 711 \times 10^3 eV$$

$$E^2 = p^2c^2 + m^2c^4 => p = \sqrt{(711 \times 10^3)^2 - (511 \times 10^3)^2} = 494.4 \times 10^3 eV/c$$

$$p = 2.637 \times 10^{-22} kg\frac{m}{s} => \lambda = \frac{h}{p} = 2.51 \times 10^{-12}m$$

3a i. -

b.

Energies	Probabilities
$E_2 = \frac{2\pi^2\hbar^2}{ma^2}$	¼
$E_4 = \frac{8\pi^2\hbar^2}{ma^2}$	3/5
$E_6 = \frac{18\pi^2\hbar^2}{ma^2}$	3/20

$$\langle E\rangle = \frac{\left(\frac{1}{4} \times 2 + \frac{3}{5} \times 8 + \frac{3}{20} \times 18\right)\pi^2\hbar^2}{ma^2} = \frac{8\pi^2\hbar^2}{ma^2}$$

c. $P\left(\frac{a}{4} \le x \le \frac{a}{2}\right) = \int_{\frac{a}{4}}^{\frac{a}{2}} |\phi_2(x)|^2 dx = \frac{2}{a}\int_{\frac{a}{4}}^{\frac{a}{2}} \sin^2\left(\frac{2\pi x}{a}\right) dx = 1/4$

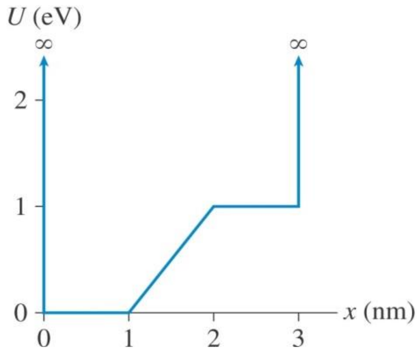
di. $E_{n_x,n_y,n_z} = \frac{\pi^2\hbar^2}{2mL^2}(n_x^2 + n_y^2 + n_z^2)$

ii. $E_{2,3,1} - E_{1,2,1} = \frac{hc}{\lambda} \Rightarrow \lambda = 2.64 \times 10^{-9} m$

iii. $[E_{2,3,1}, E_{2,1,3}, E_{1,2,3}, E_{1,3,2}, E_{3,2,1}, E_{3,1,2}] \to [E_{1,2,1}, E_{2,1,1}, E_{1,1,2}]$

iv. 18

e. Refer to lecture notes / tutorial



4. $E_{p1} + E_{p2} = E_X; P_i + 0 = P_X$

$$K + m_p c^2 + m_p c^2 = \sqrt{(m_X c^2)^2 + P_X^2 c^2}$$
$$\left(K + 2m_p c^2\right)^2 = (m_X c^2)^2 + P_i^2 c^2$$
$$(m_x c^2)^2 = \left(K + 2m_p c^2\right)^2 - P_i^2 c^2 = \left(K + 2m_p c^2\right)^2 - \left[E_{p1}^2 - m_p^2 c^4\right]$$
$$(m_x c^2)^2 = \left(K + 2m_p c^2\right)^2 - \left[\left(K + m_p c^2\right)^2 - m_p^2 c^4\right]$$
$$(m_x c^2)^2 = K^2 + 4Km_p c^2 + 4m_p^2 c^4 - \left[K^2 + 2Km_p c^2 + m_p^2 c^4 - m_p^2 c^4\right]$$
$$= 2Km_p c^2 + 4m_p^2 c^4 = 4m_p^2 c^4\left(\frac{K}{2m_p c^2} + 1\right)$$
$$m_x c^2 = 2m_p c^2 \sqrt{1 + \frac{K}{2m_p c^2}}$$

$M_Y > M_X$, Total energy of system is larger and final KE of Y is zero.