

Justify all your answers to all problems. Write clearly.

Time dilation; Length contraction: $\Delta t = \gamma \Delta t_0$; $L = L_0 / \gamma$; $c = 3 \times 10^8 \text{ m/s}$

Lorentz transformation: $x' = \gamma(x - ut)$; $y' = y$; $t' = \gamma(t - ux/c^2)$

Velocity: $v'_x = \frac{v_x - u}{1 - uv_x/c^2}$; $v'_y = \frac{v_y}{\gamma(1 - uv_x/c^2)}$; $\gamma = \frac{1}{\sqrt{1 - u^2/c^2}}$

Inverse transformations: $u \rightarrow -u$, primed \leftrightarrow unprimed; Doppler: $f' = f \sqrt{\frac{1 \pm u/c}{1 \mp u/c}}$

Momentum: $\vec{p} = \gamma m \vec{v}$; Energy: $E = \gamma mc^2$; Kinetic energy: $K = (\gamma - 1)mc^2$
 $E = \sqrt{p^2 c^2 + m^2 c^4}$; rest energy: $E_0 = mc^2$

Electron: $m_e = 0.511 \text{ MeV}/c^2$; Proton: $m_p = 938.26 \text{ MeV}/c^2$; Neutron: $m_n = 939.55 \text{ MeV}/c^2$

Atomic unit: $1u = 931.5 \text{ MeV}/c^2$; electron volt: $1eV = 1.6 \times 10^{-19} \text{ J}$

Photoelectric effect: $eV_s = K_{\text{max}} = hf - \phi = hc/\lambda - \phi$; $\phi =$ work function

Stefan law: $I = \sigma T^4$, $\sigma = 5.67037 \times 10^{-8} \text{ W/m}^2 \cdot \text{K}^4$; Wien's law: $\lambda_m T = 2.8978 \times 10^{-3} \text{ m} \cdot \text{K}$

$I(T) = \int_0^\infty I(\lambda, T) d\lambda$; $I = (c/4)u$; $u(\lambda, T) = N(\lambda)E_{\text{av}}(\lambda, T)$; $N(\lambda) = \frac{8\pi}{\lambda^4}$

Boltzmann distribution: $N(E) = Ce^{-E/kT}$; $N = \int_0^\infty N(E) dE$; $E_{\text{av}} = \frac{1}{N} \int_0^\infty EN(E) dE$

Classical: $E_{\text{av}} = kT$; Planck: $E_n = n\varepsilon = nhf$; $N = \sum_{n=0}^\infty N(E_n)$; $E_{\text{av}} = \frac{1}{N} \sum_{n=0}^\infty E_n N(E_n)$

Planck: $E_{\text{av}} = \frac{hc/\lambda}{e^{hc/\lambda kT} - 1}$; $hc = 1,240 \text{ eV} \cdot \text{nm}$; $\lambda_m T = hc/4.96k$; $\sigma = \frac{2\pi^5 k^4}{15c^2 h^3}$

Boltzmann constant: $k = (1/11,604) \text{ eV/K}$; $1\text{\AA} = 1\text{A} = 0.1 \text{ nm}$

Compton scattering: $\lambda' - \lambda = \frac{h}{m_e c} (1 - \cos\theta)$; $\frac{h}{m_e c} = 0.0243 \text{ A}$

de Broglie: $\lambda = \frac{h}{p}$; $f = \frac{E}{h}$; $\omega = 2\pi f$; $k = \frac{2\pi}{\lambda}$; $E = \hbar\omega$; $p = \hbar k$; $E = \frac{p^2}{2m}$

Uncertainty: $\Delta x \Delta k \sim 1$; $\Delta t \Delta \omega \sim 1$; $\Delta x \Delta p \sim \hbar$; $\Delta t \Delta E \sim \hbar$; $\Delta A = \sqrt{\langle A^2 \rangle - \langle A \rangle^2}$
 $\hbar c = 197.3 \text{ eV nm}$