NORTHERN ILLINOIS UNIVERSITY

PHYSICS DEPARTMENT

Physics 283 – Modern Physics   Spring 2025

Quiz #1

INSTRUCTIONS:

1. No graphic calculators are allowed for this quiz.
2. Do all your work in the examination blue booklet
3. You may find the following formulas useful:

Galilean relativity	$x' = x - ut, v'_x = v_x - u$	2.1
Einstein's postulates	(1) The laws of physics are the same in all inertial frames. (2) The speed of light has the same value c in all inertial frames.	2.3
	$\Delta t = \dfrac{\Delta t_0}{\sqrt{1-u^2/c^2}}$ (Δt_0 = proper time)	2.4
	$L = L_0\sqrt{1-u^2/c^2}$ (L_0 = proper length)	2.4
	$v = \dfrac{v' + u}{1 + v'u/c^2}$	2.4
	$f' = f\sqrt{\dfrac{1-u/c}{1+u/c}}$	2.4
	$x' = \dfrac{x - ut}{\sqrt{1-u^2/c^2}}$, $y' = y$, $z' = z$, $t' = \dfrac{t - (u/c^2)x}{\sqrt{1-u^2/c^2}}$	2.5

$$v'_x = \frac{v_x - u}{1 - v_x u/c^2},$$

$$v'_y = \frac{v_y\sqrt{1-u^2/c^2}}{1 - v_x u/c^2},$$

$$v'_z = \frac{v_z\sqrt{1-u^2/c^2}}{1 - v_x u/c^2}$$

$$\Delta t' = \frac{uL/c^2}{\sqrt{1-u^2/c^2}}$$

$$\vec{\mathbf{p}} = \frac{m\vec{\mathbf{v}}}{\sqrt{1-v^2/c^2}}$$

$$K = \frac{mc^2}{\sqrt{1-v^2/c^2}} - mc^2$$

$$E_0 = mc^2$$

$$E = K + E_0 = \frac{mc^2}{\sqrt{1-v^2/c^2}}$$

$$E = \sqrt{(pc)^2 + (mc^2)^2}$$

$$E \cong pc$$

Conservation laws	In an isolated system of particles, the total momentum and the relativistic total energy remain constant.

$y_n = n\frac{\lambda D}{d} \quad n = 0, 1, 2, 3, \ldots$	3.1
$2d\sin\theta = n\lambda \quad n = 1, 2, 3, \cdots$	3.1
$E = hf = hc/\lambda$	3.2
$K_{\max} = eV_s = hf - \phi$	3.2
$\lambda_c = hc/\phi$	3.2
$I = \sigma T^4$	3.3
$\lambda_{\max}T = 2.8978 \times 10^{-3}\ \text{m}\cdot\text{K}$	3.3

$$I(\lambda) = \frac{2\pi c}{\lambda^4}kT$$

$$I(\lambda) = \frac{2\pi hc^2}{\lambda^5}\frac{1}{e^{hc/\lambda kT} - 1}$$

$$\frac{1}{E'} - \frac{1}{E} = \frac{1}{m_e c^2}(1 - \cos\theta),$$

$$\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta)$$

$$\lambda_{\min} = hc/K = hc/e\Delta V$$

$$hf = E_+ + E_- = (m_e c^2 + K_+) + (m_e c^2 + K_-)$$

$$(m_e c^2 + K_+) + (m_e c^2 + K_-) = E_1 + E_2$$

$\lambda = h/p$	4.1
$a\sin\theta = n\lambda \quad n = 1, 2, 3, \ldots$	4.2
$\Delta x\Delta\lambda \sim \varepsilon\lambda^2$	4.3
$\Delta f\,\Delta t \sim \varepsilon$	4.3
$\Delta x\Delta p \geq \hbar/2$	4.4
$\Delta E\Delta t \geq \hbar/2$	4.4

Statistical momentum uncertainty	$\Delta p_x = \sqrt{(p_x^2)_{av} - (p_{x,av})^2}$	4.4
Wave packet (discrete k)	$y(x) = \sum A_i \cos k_i x$	4.5
Wave packet (continuous k)	$y(x) = \int A(k)\cos kx\, dk$	4.5
Group speed of wave packet	$v_{\text{group}} = \frac{d\omega}{dk}$	4.6

Balmer formula	$\lambda = (364.5\ \text{nm})\frac{n^2}{n^2 - 4}$ $(n = 3, 4, 5, \ldots)$	6.4
Radii of Bohr orbits in hydrogen	$r_n = \frac{4\pi\varepsilon_0\hbar^2}{me^2}n^2 = a_0 n^2$ $(n = 1, 2, 3, \ldots)$	6.5
Energies of Bohr orbits in hydrogen	$E_n = -\frac{me^4}{32\pi^2\varepsilon_0^2\hbar^2}\frac{1}{n^2} = \frac{-13.60\ \text{eV}}{n^2} \quad (n = 1, 2, 3, \ldots)$	6.5

$\Delta l = m\lambda$, for $m = 0, \pm 1, \pm 2, \pm 3...$

$\Delta l = (m + \frac{1}{2})\lambda$, for $m = 0, \pm 1, \pm 2, \pm 3...$

$\Delta l = d \sin\theta$

$d \sin\theta = m\lambda$, for $m = 0, \pm 1, \pm 2, \pm 3, \ldots$

$d \sin\theta = (m + \frac{1}{2})\lambda$, for $m = 0, \pm 1, \pm 2, \pm 3, \ldots$

$y_m = \frac{m\lambda D}{d}$

$\Delta d = m\frac{\lambda_0}{2}$

$a \sin\theta = m\lambda$ for $m = \pm 1, \pm 2, \pm 3, \ldots$

$\beta = \frac{\phi}{2} = \frac{\pi a \sin\theta}{\lambda}$

$E = N\Delta E_0 \frac{\sin\beta}{\beta}$

$I = I_0 \left(\frac{\sin\beta}{\beta}\right)^2$

$\theta = 1.22\frac{\lambda}{D}$

$m\lambda = 2d\sin\theta$, $m = 1, 2, 3...$

$c = 3 \times 10^8$ meters/sec

$e = 1.602 \times 10^{-19}\,\mathrm{C}$

$h = 6.626 \times 10^{-34}\,\mathrm{J \cdot sec}$

$hc = 1240\,\mathrm{eV \cdot nm}$

$1\ \mathrm{\AA} = 10^{-10}$ meters

$1\,\mathrm{eV} = 1.602 \times 10^{-19}\,\mathrm{J}$

$\sigma = 5.67037 \times 10^{-8}\,\mathrm{W/(m^2K^4)}$

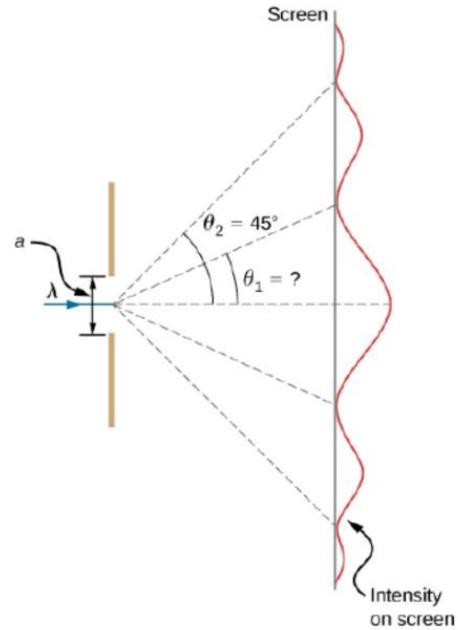
Centigrade to Kelvins conversion: $T = 273.15 + °C$

Show all your work in the solution of each problem.

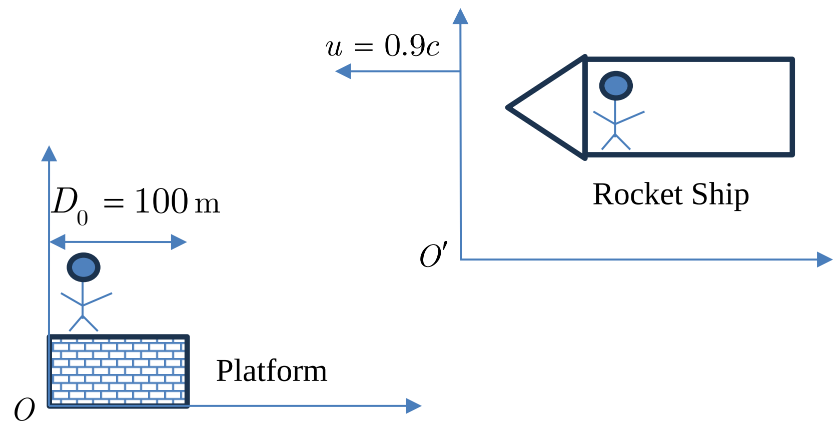
Writing down a number with no work shown gets no credit.

Put each problem on a separate page in the blue booklet.

Problem 1 (25 points)



Visible light of wavelength 600 nm falls on a single slit and produces its second diffraction minimum at an angle of 45° relative to the incident direction of the light, as shown above. What is the width of the slit?



Problem 2 (25 points)

An observer O is standing on a platform of length $D_0 = 100\,\mathrm{m}$ on a space station. A rocket passes at a relative speed of 0.90c moving parallel to the edge of the platform. The observer O notes that the front and back of the rocket simultaneously line up with the ends of the platform at a particular instant.

(a) According to observer O', what is the length of his space ship?

(b) According to observer O', what is the length of the platform?

(c) According to O, what is the time necessary for the rocket to pass a particular point on the platform?

(d) According to O', how long does it take for observer O to pass the entire length of the rocket?

Problem 3 (25 points)

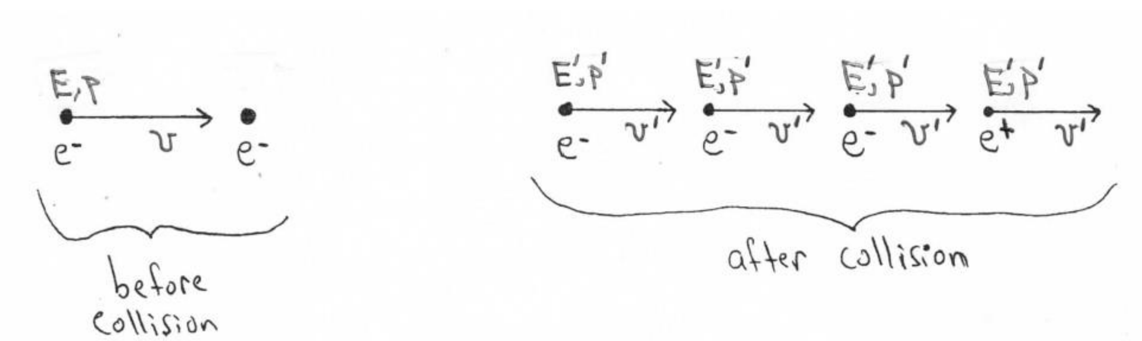
Blackbody thermal radiation:

(a) At what wavelength does a room-temperature $(T = 25°\mathrm{C})$ object emit the maximum thermal radiation?

(b) To what temperature must we heat it until its peak thermal radiation is in the red region of the spectrum $(\lambda = 600\,\mathrm{nm})$?

(c) How many times as much thermal radiation does it emit at the higher temperature?

Problem 4 (25 points)



A moving electron collides with a stationary electron and an electron-positron pair comes into being as a result. The rest mass energy of an electron is $mc^2 = 0.511$ MeV.

(a) Write down the conservation of energy relation for this scattering problem (use the symbols given in figure above).

(b) Write down the conservation of momentum relation for this scattering problem. (use the symbols given in figure above)

(c) Find the minimum (threshold) kinetic energy needed by the incident electron to produce the 3 electrons and a positron. (express the result in MeV).