Quantity	**Symbol**	**Value**
Coulombs Constant	$k_C = 1/4\pi\epsilon_o$	$8.98 \times 10^9\,\mathrm{Nm^2/C^2}$
Electron Mass	m_e	$9.1 \times 10^{-31}\,\mathrm{kg}$
Electron Charge	e	$-1.6 \times 10^{-19}\,\mathrm{C}$
Electron Volt	eV	$1.6 \times 10^{-19}\,\mathrm{J}$
Permitivity	ϵ_o	$8.85 \times 10^{-12}\,\frac{\mathrm{C^2}}{\mathrm{Nm^2}}$
Magnetic Permeability	μ_o	$4\pi \times 10^{-7}\,\mathrm{N \cdot A^2}$
Speed of Light	c	$3.0 \times 10^8\,\mathrm{m/s}$
Planck's Constant	h	$6.6 \times 10^{-34}\mathrm{m^2 kg/s}$

Integrals	**Value**	
$\int_{-\infty}^{\infty} du\, e^{-\alpha u^2}$	$\sqrt{\frac{\pi}{\alpha}}$	
$\int_{-\infty}^{\infty} du\, u^2 e^{-\alpha u^2}$	$\frac{1}{2\alpha}\sqrt{\frac{\pi}{\alpha}}$	
$\int_0^{\infty} du\, u^n e^{-\alpha u}$	$\frac{n!}{\alpha^{n+1}}$	
$\int du\, \sin^2(\alpha u)$	$\frac{u}{2} - \frac{\sin(2\alpha u)}{4\alpha}$	
$\int du\, \cos^2(\alpha u)$	$\frac{u}{2} + \frac{\sin(2\alpha u)}{4\alpha}$	
$\int_{-\frac{1}{2}}^{+\frac{1}{2}} du u^2 \sin^2(n\pi u)$	$\frac{-6+n^2\pi^2}{24n^2\pi^2}$	$n = 2, 4, 6, 8$
$\int_{-\frac{1}{2}}^{+\frac{1}{2}} du u^2 \cos^2(n\pi u)$	$\frac{-6+n^2\pi^2}{24n^2\pi^2}$	$n = 1, 3, 5, 7$
$\int (\cos(\theta))^\alpha \sin(\theta) d\theta$	$\frac{-1}{\alpha+1}\,(\cos(\theta))^{\alpha+1}$	
$\int (\sin(\theta))^\alpha \cos(\theta) d\theta$	$\frac{+1}{\alpha+1}\,(\sin(\theta))^{\alpha+1}$	

You have an electron which moves around a proton. Start from newtons law, the coulomb law, and the Bohr quantization condition for the angular momentum.

1. (Symbol) Determine the velocity and radius of the $n - th$ orbit.

2. (Symbol) Determine the orbital period (*i.e.* the time per revolution) of the n-th orbit.

3. (Symbol) Classically the electron in circular orbit would radiate electro magnetic waves due to acceleration. Recall that in the classical limit, the energy lost to electromagnetic waves per unit time is

$$\frac{dE}{dt} = \frac{2}{3}\frac{e^2}{4\pi\epsilon_o}\frac{a^2}{c^3} \tag{1}$$

   where a is the acceleration. Using this formula, determine the energy lost per unit time by the electron in the n-th orbit

4. (Symbol) Determine the energy lost during the time of one revolution.

5. (Number) Evaluate the energy lost per revolution (part (4)) numerically in electron volts for the $n = 3$ orbit. Qualitatively how does the energy lost per revolution compare to the total energy of the orbit.

Consider making a model of a proton inside a nucleus as a single proton bouncing around in a box potential, i.e. imagine that each proton is moves independently, but feels a box potential created by all the other protons and neutrons. The box has length a and is given

$$V(x) = \begin{cases} 0 & x < \left|\frac{a}{2}\right| \\ V_o = \infty & x > \left|\frac{a}{2}\right| \end{cases} \tag{2}$$

as shown below.

1. (Number) What is a typical nuclear radius. What is the proton mass in MeV/c^2.

2. (Symbol+Number) Take the box size to be the circumference associated with the radius estimated in (a). Determine the energy of the photon that is emitted when the proton decays from the first excited state down to the ground state.

3. (Sentence) Explain qualitatively why the average momentum $\bar{p} = 0$ is zero for the particle in the box.

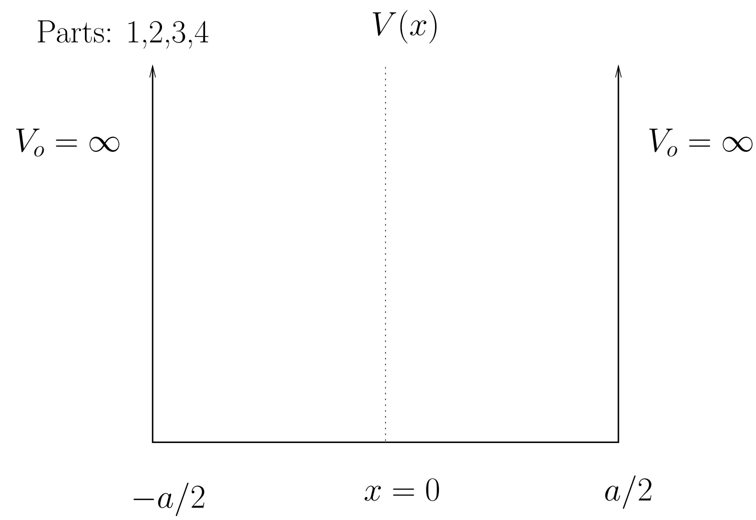
4. (Symbol + Sentence) For the first excited state compute $\overline{p^2}$ and the variance of the momentum Δp. Qualitatively interpret your result for Δp with the uncertainty principle.

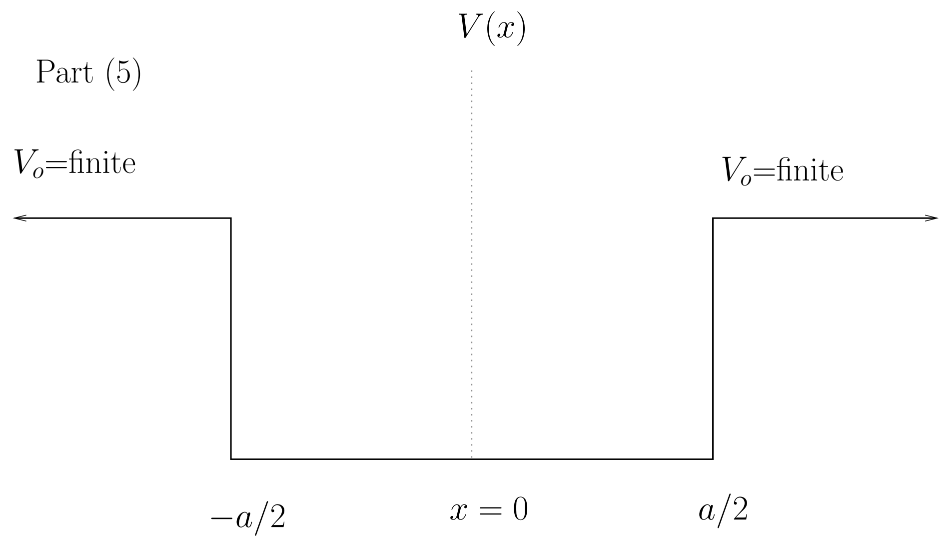
5. (Graph) Suppose the potential V_o was *not* infinite, i.e. $V_o \neq \infty$ but still large. Qualitatively sketch the ground state and the first and second excited states and there associated probability densities. (Six graphs in all)

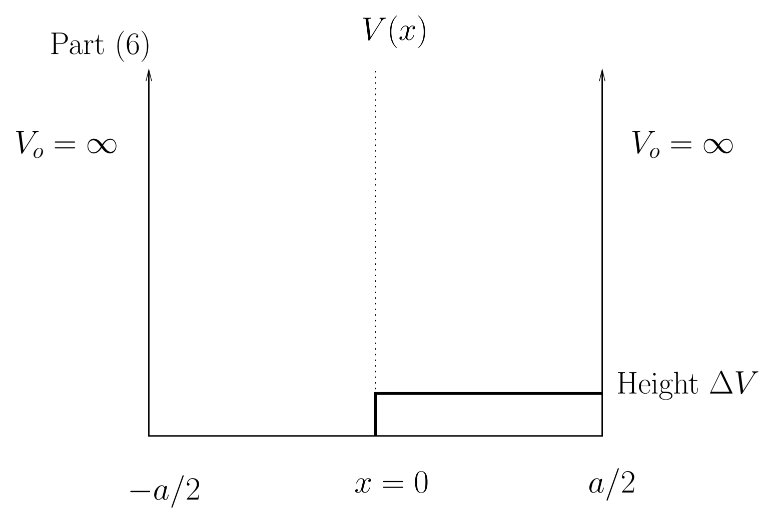
6. (Symbol) Now return to the $V_o = \infty$ and suppose that small constant perturbing potential ΔV is added to the square well. The region of excess potential fills up half the box as shown below.

   (a) Under what conditions may ΔV be considered small, i.e. it is small compared to something? What is that something?

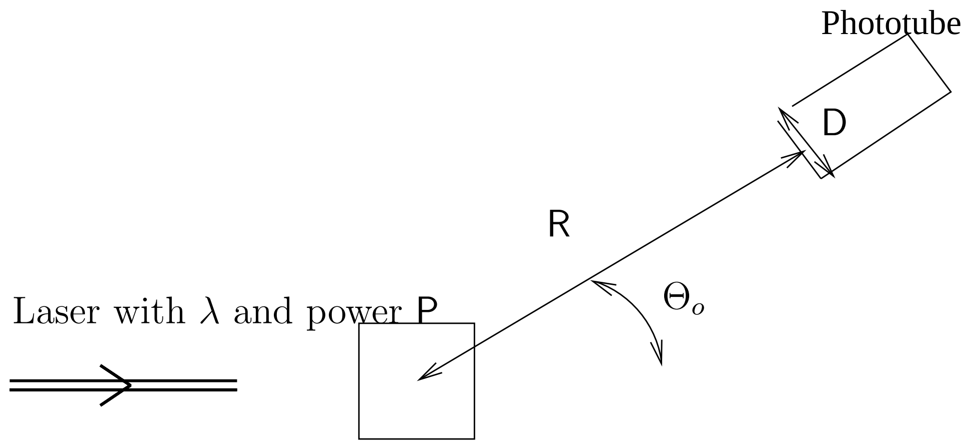
   (b) Determine the energy shift to the first excited state due to this perturbing potential.


Parts: 1,2,3,4
$V(x)$
$V_o = \infty$
$V_o = \infty$
$-a/2$
$x = 0$
$a/2$


$V(x)$
Part (5)
V_o=finite
V_o=finite
$-a/2$
$x = 0$
$a/2$


Part (6)
$V(x)$
$V_o = \infty$
$V_o = \infty$
Height ΔV
$-a/2$
$x = 0$
$a/2$

A reasonably powerful helium-neon laser (with total power, P, and wavelength λ) is pointed at a glass cell containing an unknown gas. A fraction f, of the total power entering the cell is scattered uniformly in all directions. The wavelength is unchanged in the scattering process.



A phototube counts the scattered photons, and the front face of the phototube has a small circular opening of diameter D. The phototube is situated a distance of R from the interaction region at an angle Θ_o as shown below.

Except for part (1), give all answers in terms of the parameters of this problem: P, f, λ, D, R, Θ_o .

1. Assuming that $D \simeq 2\,\text{cm}$ and $R \simeq 40\,\text{cm}$ evaluate the solid angle subtended by the detector.

2. Determine the number of photons per second collected by the phototube.

3. Determine the total number of photons scattered per second into an angle *less than* Θ_o.

4. For small Θ_o determine a Taylor series expansion for part (3), i.e. determine the number scattered with angle less than Θ_o for small Θ_o.