

Final Exam Friday May 15, 2pm - 4:30pm **GOOD LUCK!**

Final Exam Room Assignments:

A-Can. Humanities 1003

Car-Franc. Humanities 1006

Franz-Hsu. Javits 101

Hua-Mon. Javits 102

Mor - K. Patel. Javits 103

M. Patel - Sari. Javits 109

Sarm - Tang. Javits 111

Taq - Z. Light Engineering 102

The next 7 slides show the main ideas of chapters 23-27, plus two extra slides showing some potential energy curves and corresponding quantum wavefunctions (actually just the "real" part of the total complex wave function.)

Ch 23 -- The Main Ideas

$$T = T_0 / \sqrt{1 - \left(\frac{v}{c}\right)^2}$$

time dilation

$$L = L_0 \sqrt{1 - \left(\frac{v}{c}\right)^2}$$

length contraction

$$m = m_0 / \sqrt{1 - \left(\frac{v}{c}\right)^2}$$

mass increase

$$E = \frac{m_0 c^2}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} = mc^2$$
$$= \sqrt{(m_0 c^2)^2 + (pc)^2}$$

$c = 3.00 \times 10^8$ m/s is the same in all frames.

T_0 = proper time - other times are longer

L_0 = proper length - other lengths are shorter

m_0 = rest mass

$m_0 c^2$ = rest energy

mc^2 = total energy = rest energy plus kinetic

rest energy of a composite particle is the sum of rest energy of constituents plus binding energy.

Ch 24 --The main ideas

1. Atoms are made from squishy light electrons and massive, hard, tiny, nuclei.
2. Sizes $1-2 \times 10^{-10}$ m and $1-7 \times 10^{-15}$ m.
3. Coulomb's law forces $F = kq_1q_2/r_{12}^2$ operate and hold the atom together.
4. Electrons have $q = -e$, nuclei $q = +Ze$
5. Potential energy of Coulomb forces is $V = kq_1q_2/r_{12}$
6. X-rays diffract from crystal planes.
7. Fundamental law of decay: rate of loss = $-dN/dt = \lambda N$. This implies $N = N_0e^{-\lambda t}$. Decay constant λ has units s^{-1} .

The constants of nature:

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

$$m = 0.911 \times 10^{-30} \text{ kg}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

$$M_u = 1.66 \times 10^{-27} \text{ kg}$$

$$N_A = 6.023 \times 10^{23}$$

$$k_B = 1.38 \times 10^{-23} \text{ J/K}$$

$$k = 9.00 \times 10^9 \text{ Nm}^2/\text{C}^2$$

Ch 25 -- The main ideas

1. Light has particle properties.
2. photon energy = $hf = hc/\lambda$
3. particles have wave properties
4. $p = h/\lambda$ (always - light, electrons, relativistic, non-relativistic)
5. Electrons in atoms have discrete energy levels
6. Light is emitted or absorbed when electrons change level.
7. Bohr model - oversimplified but useful.

The constants of nature:

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

$$m = 0.911 \times 10^{-30} \text{ kg}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

$$h = 6.63 \times 10^{-34} \text{ Js}$$

$$hc = 1.24 \times 10^{-6} \text{ eV m}^*$$

$$M_u = 1.66 \times 10^{-27} \text{ kg}$$

$$N_A = 6.023 \times 10^{23}$$

$$k_B = 1.38 \times 10^{-23} \text{ J/K}$$

$$k = 9.00 \times 10^9 \text{ Nm}^2/\text{C}^2$$

*unnecessary; perhaps unwise to use short cuts like this.

Ch 26 -- The main ideas

1. Particles need a wave description.
2. Waves cannot be localized and still have good wavelengths. Therefore $\Delta p \Delta x \geq h/2\pi$.
3. Waves cannot change in time and still have good frequencies. Therefore $\Delta E \Delta t \geq h/2\pi$.
4. Newtonian energy $E = p^2/2m + V(r)$ is not abandoned, but changed (i.e. $p = h/\lambda$).
5. Particle in a box. $V(r) = 0$ inside. $E = (1/2m)(h/\lambda)^2$, and $\lambda = 2L/n$.
6. Wave function ψ .
7. Quantum numbers like "n" reflect the number of nodes; close analog of classical standing waves.
8. Barrier penetration; tunneling.

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$$m = 0.911 \times 10^{-30} \text{ kg}$$

$$c = 3.00 \times 10^8 \text{ m/s}$$

$$h = 6.63 \times 10^{-34} \text{ Js}$$

$$hc = 1.24 \times 10^{-6} \text{ eV m}^*$$

$$E_n = -13.6 \text{ eV}/n^{2**}$$

$$M_u = 1.66 \times 10^{-27} \text{ kg}$$

$$N_A = 6.023 \times 10^{23}$$

$$k_B = 1.38 \times 10^{-23} \text{ J/K}$$

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** special to hydrogen but useful more generally.

Potential energy "wells" - a natural concept in Newtonian and Quantum physics

Standing wave normal modes.

The infinite square well is the favorite example, but only because the wave functions are simple, like guitar string normal modes.

Quantum numbers assigned by "node counting." Trickier in $d = 3$.

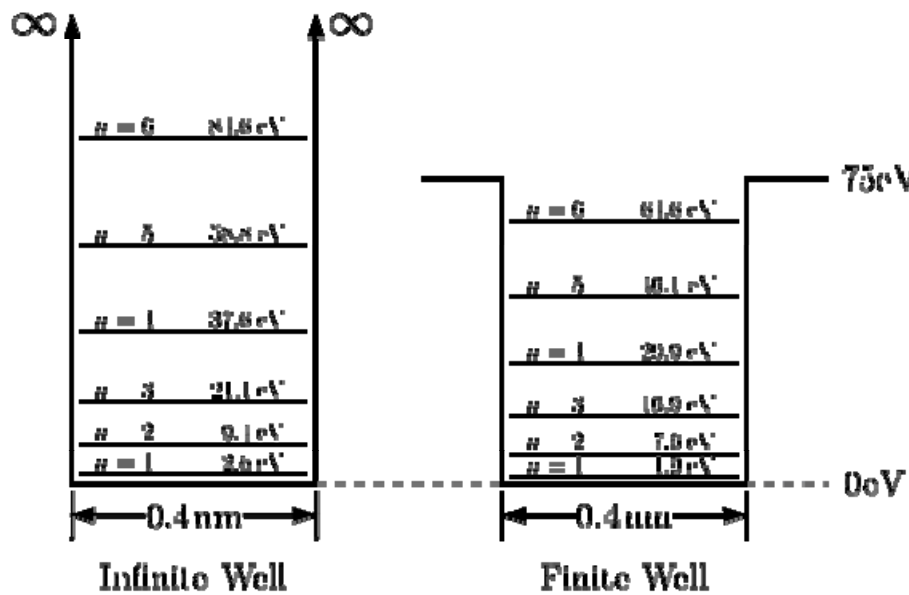
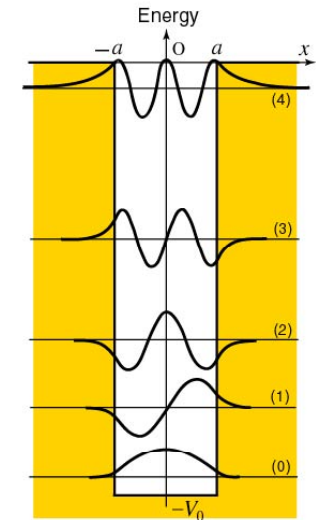
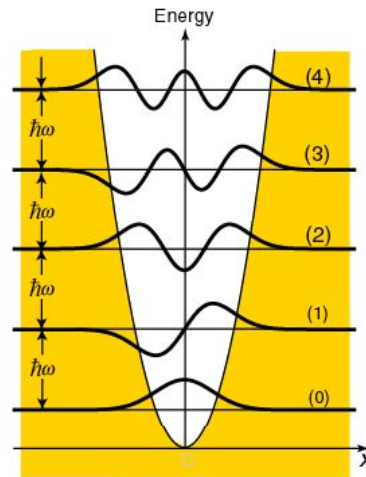


Fig. (C)

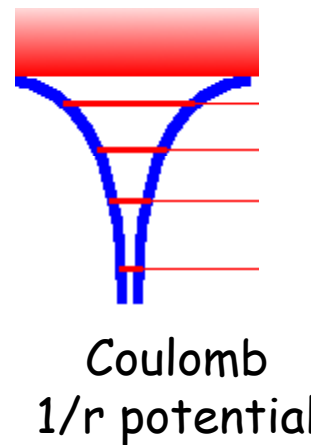


The thick solid curves are the wave functions.
(0) : the ground state
(1) (2) (3) ... : the excited states

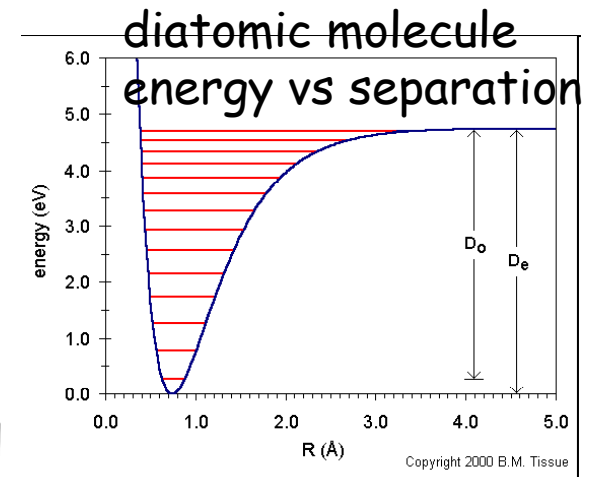
For the finite well, ψ "leaks" a bit under the barrier.



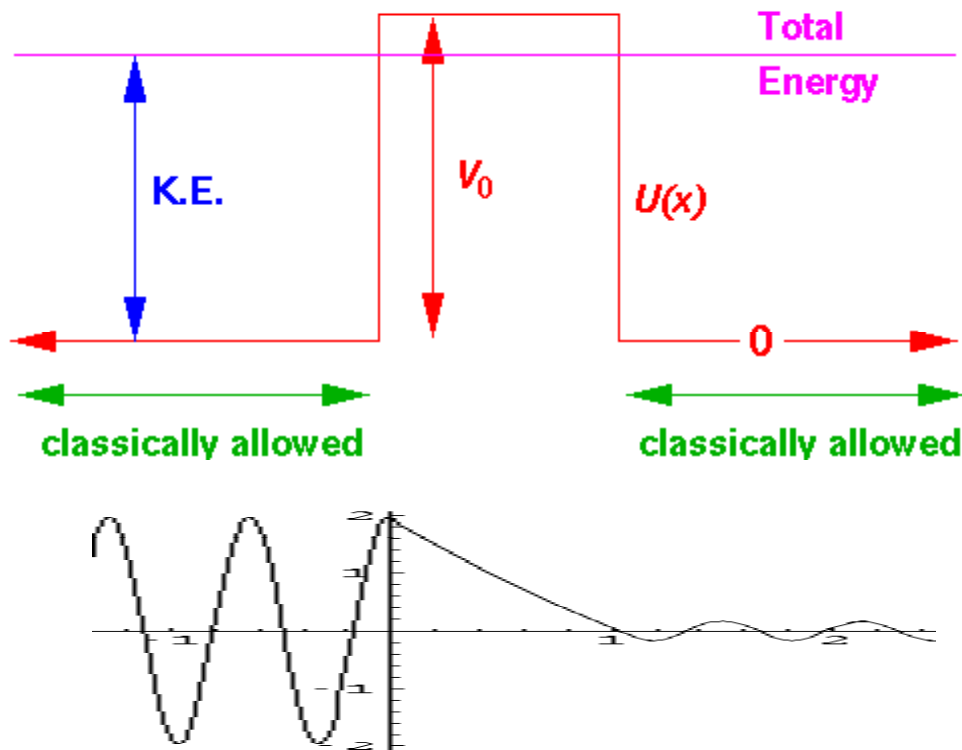
The thick solid curves are the wave functions.
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Coulomb $1/r$ potential



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$$KE = E - V(x) = p^2 / 2m$$

$$p = \sqrt{2m(E - V(x))}$$

"Under the barrier" the momentum is imaginary, call it $i|p|$. The wave function is exponentially decaying, like $\psi \sim e^{-2\pi|p|x/h}$. The tunnel probability is like $|\psi|^2$.

Tunnel effect

The top picture is potential energy versus x coordinate. A particle is coming in from the left with momentum $p = h/\lambda$. Its kinetic energy $p^2/2m$ is less than the barrier height V_0 .

Its wave function is shown in the lower picture. Under the barrier, the wave function is decaying exponentially. But since the barrier is not infinitely "thick", there is still something left when it reaches the other side of the barrier. The probability of getting through is about 0.03.

Ch 27 -- The main ideas

1. Nuclei are built from "nucleons" (protons and neutrons)
2. Coulomb repulsion between protons is still working at $r < 10^{-15}$ m.
3. Additional forces are needed.
4. Strong nuclear force binds nucleons to neighboring nucleons.
5. Weak nuclear force allows $n \rightarrow p^+ + e^- + \bar{\nu}$
6. also allows $p^+ \rightarrow n + e^+ + \nu$
7. α decay: ${}^A_Z X \rightarrow {}^{A-4}_{Z-2} X' + {}^4_2 \text{He}$
8. β decay: ${}^A_Z X \rightarrow {}^A_{Z+1} X' + e^- + \bar{\nu}$
9. γ decay: nucleus relaxes toward ground state by photon emission.
10. Nuclear decays conserve energy, momentum, charge, nucleon number.
11. $E=mc^2$ contains rest AND binding energy.
12. Energy release by fission can happen when $A > 56$
13. Energy release by fusion can happen when $A < 56$.

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$$c = 3.00 \times 10^8 \text{ m/s}$$

$$h = 6.63 \times 10^{-34} \text{ Js}$$

$$c^2 = 931.5 \text{ MeV/u}^*$$

$$M_u = 1.66 \times 10^{-27} \text{ kg}$$

$$N_A = 6.023 \times 10^{23}$$

$$k_B = 1.38 \times 10^{-23} \text{ J/K}$$

$$k = 9.00 \times 10^9 \text{ Nm}^2/\text{C}^2$$

*too useful not to keep