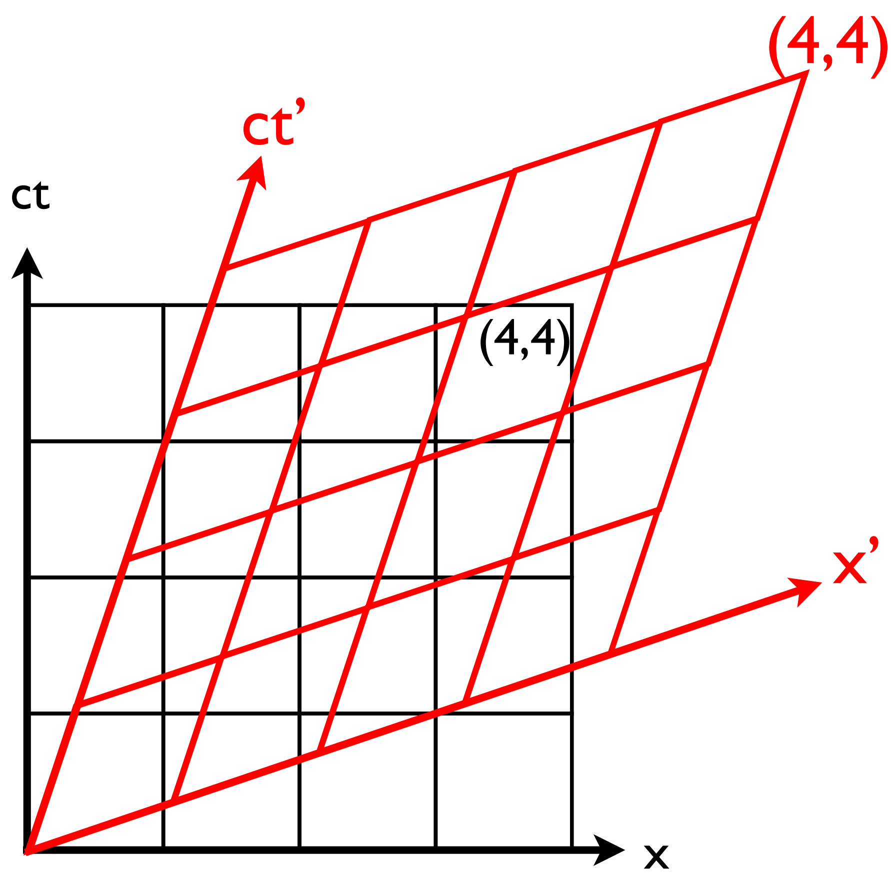
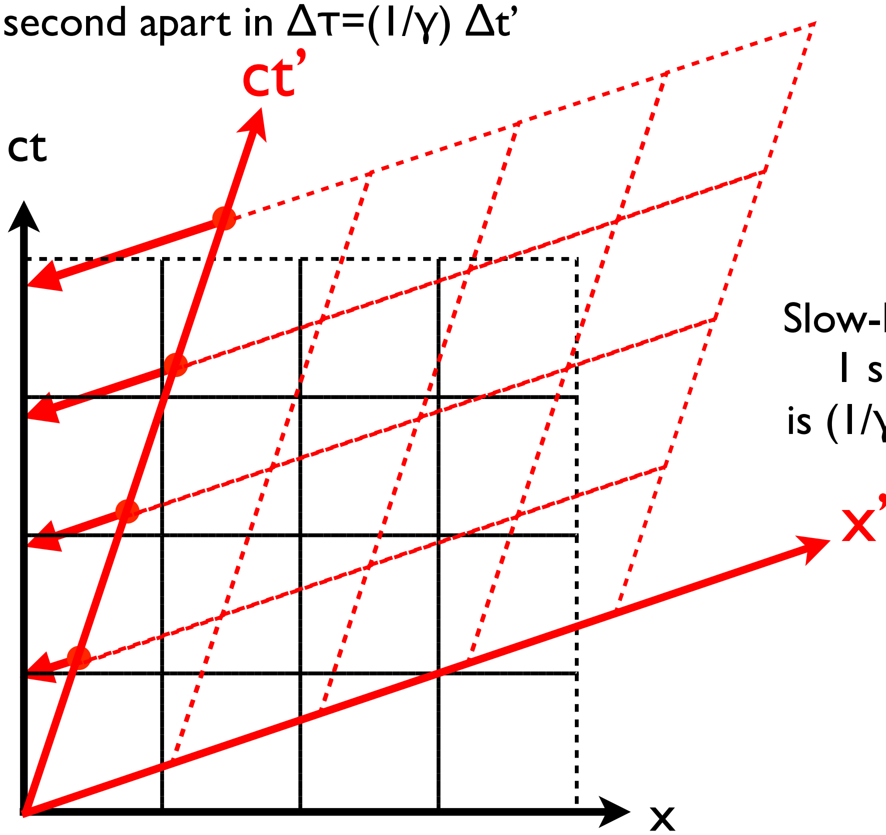
Lecture 24

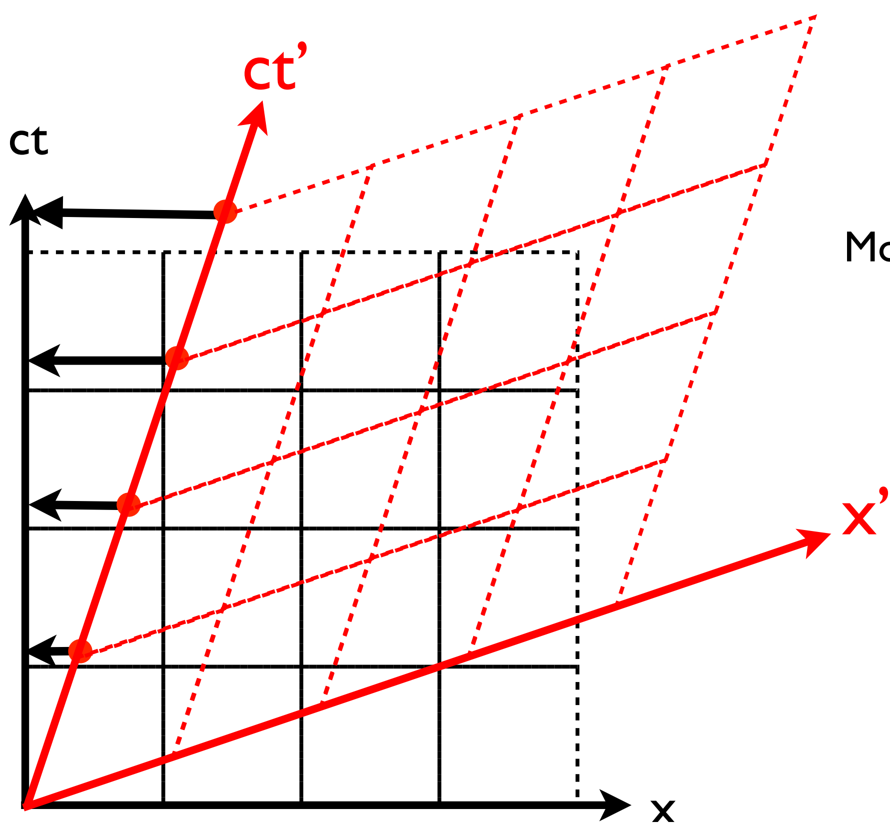


Proper Time: Events that are 1 second apart in S' are less than 1 second apart in $\Delta\tau=(1/\gamma)\,\Delta t'$



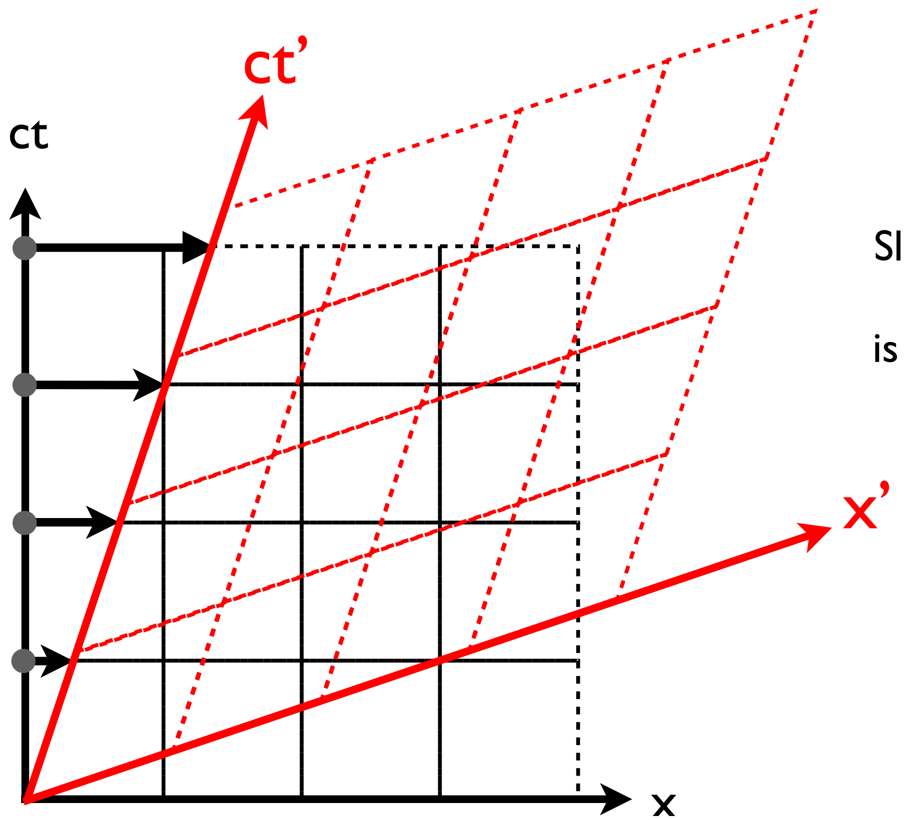
Slow-Motion:
1 s in S'
is $(1/\gamma)$ s in S

Time Dilation: Events that are spaced 1 second apart in S' are are spaced more than 1 second apart in S ($\Delta ct=(\gamma)\,\Delta ct'$)



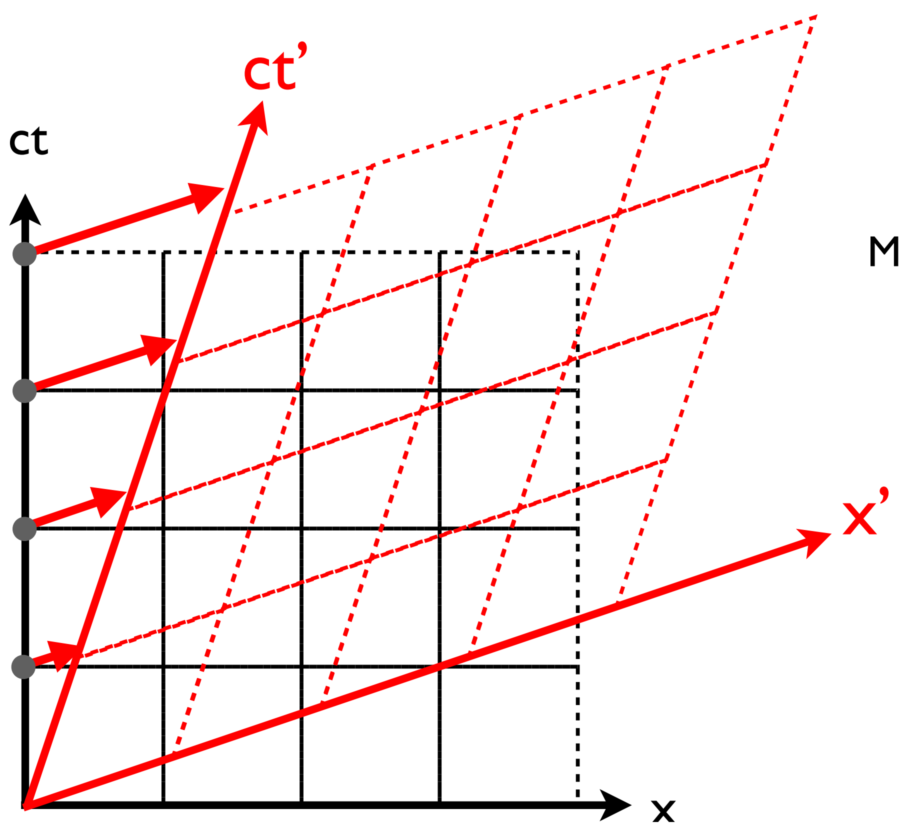
Moving clocks
run slow

Proper Time: Events that are 1 second apart in S are less than 1 second apart in S' ($\Delta\tau'=(1/\gamma)\ \Delta t$)



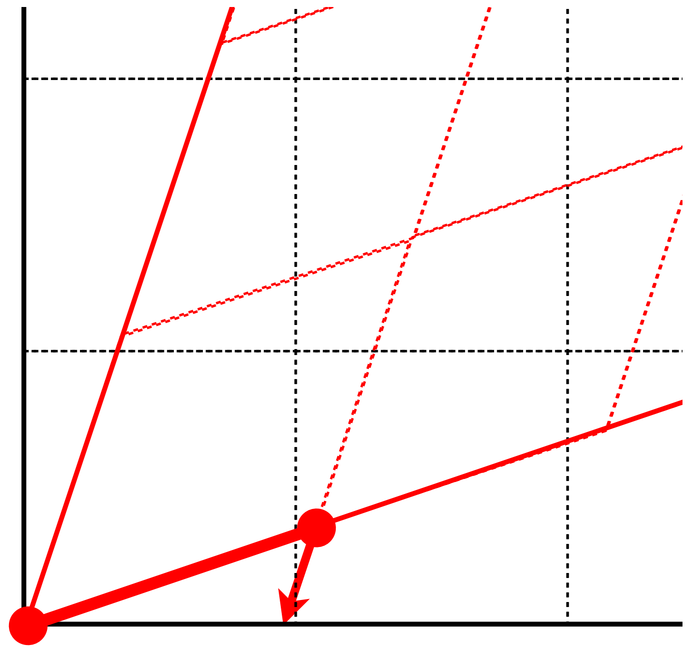
Slow-Motion:
1 s in S
is $(1/\gamma)$ s in S'

Time Dilation: Events that are spaced 1 second apart in S are are spaced more than 1 second apart in S' ($\Delta ct'=\gamma\ \Delta ct$)



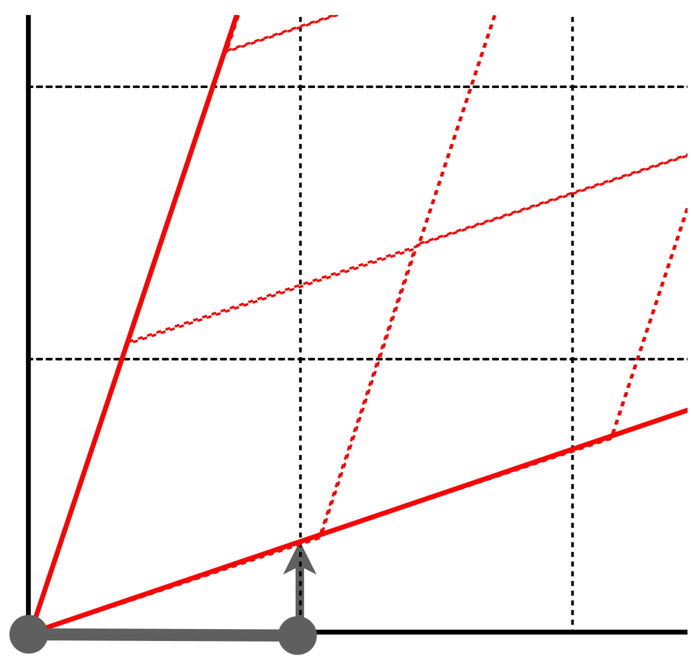
Moving clocks
run slow

Length Contraction: Objects that are 1 meter long in S' appear less than 1 meter long in S ($\Delta x=(1/\gamma)\ \Delta x'$)



Length measurements must be made <u>at the same time</u> in an IRF

Length Contraction: Objects that are 1 meter long in S appear less than 1 meter long in S' ($\Delta x'=(1/\gamma)\ \Delta x$)



Length measurements must be made <u>at the same time</u> in an IRF

Clicker Question

Terra (who is standing on the ground) starts his stopwatch at the instant that Stella flies past him in her spaceship.

Later, according to Stella, at the instant that Terra's stopwatch reads 8.0 s, Stella's stopwatch reads 10.0 s.

According to *Stella*, her spaceship is 100 m long (along the direction of motion). According to *Terra*, the length of Stella's spaceship is:

A) 64 m.

B) 80 m.

C) 100 m.

D) 125 m.

E) none of the above

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Terra (who is standing on the ground) starts his stopwatch at the instant that Stella flies past him in her spaceship.

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$\boxed{\text{B) 80 m.}}$

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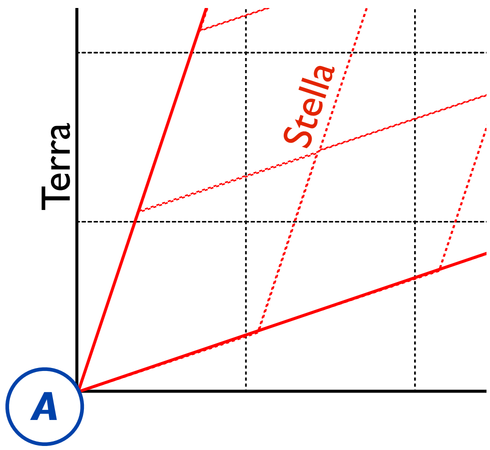
Clicker Question

Terra (who is standing on the ground) starts his stopwatch at the instant that Stella flies past him in her spaceship. A

According to Stella, at the instant that Terra's stopwatch reads 16.0 s, Stella's stopwatch reads 20.0 s.

According to ***Terra***, at the instant that *Stella's* stopwatch reads 20.0 s, ***Terra's*** stopwatch reads:

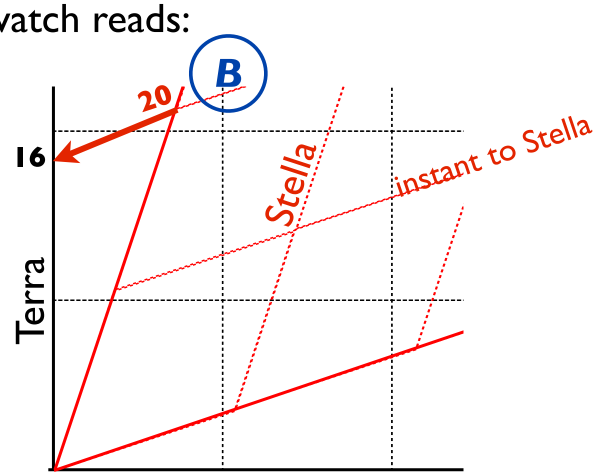


Clicker Question

Terra (who is standing on the ground) starts his stopwatch at the instant that Stella flies past him in her spaceship.

According to Stella, at the instant that Terra's stopwatch reads 16.0 s, Stella's stopwatch reads 20.0 s. B

According to ***Terra***, at the instant that *Stella's* stopwatch reads 20.0 s, ***Terra's*** stopwatch reads:



Slow-Motion:
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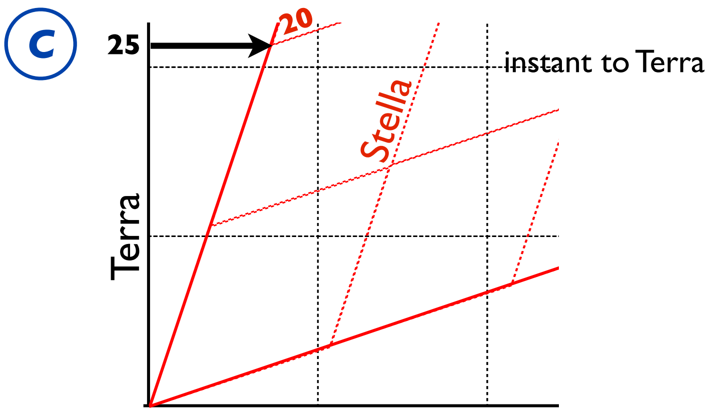

Moving clocks run slow:
$\Delta ct = (\gamma)\, \Delta ct'$

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According to Stella, at the instant that Terra's stopwatch reads 16.0 s, Stella's stopwatch reads 20.0 s.

According to *Terra*, at the instant that *Stella's* stopwatch reads 20.0 s, *Terra's* stopwatch reads:

A. 16.0 s.

B. 20.0 s.

C. 25.0 s.

D. none of the above

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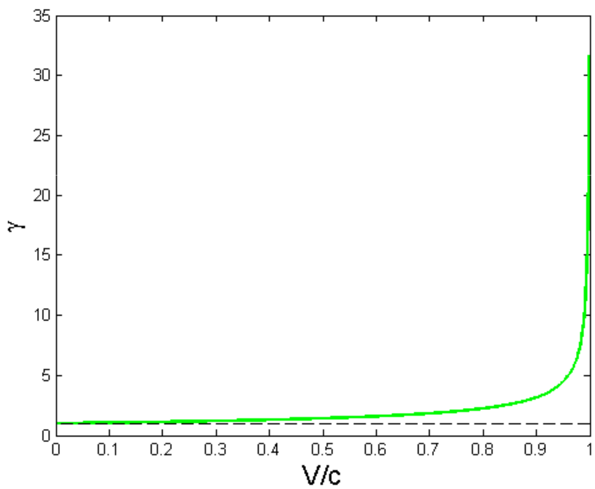
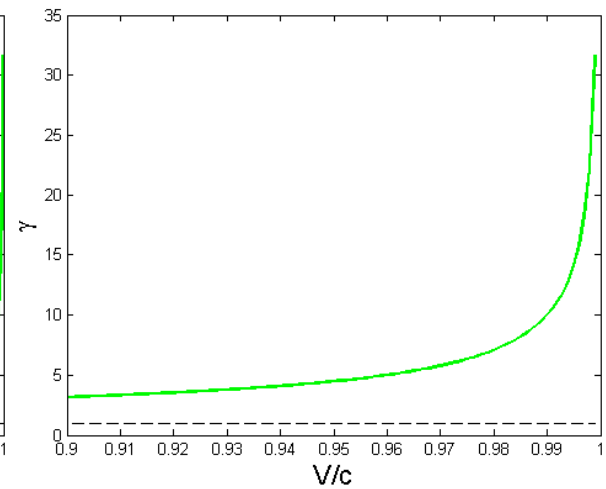
http://math.ucr.edu/~jdp/Relativity/Bug_Rivet.html

Lecture 25

$$\gamma = \frac{1}{\sqrt{1-\frac{V^2}{c^2}}}$$





Clicker Question

According to the relativistic expression for momentum, if the speed of an object is doubled, the magnitude of its momentum

A) increases by a factor greater than 2

B) increases by a factor of 2

C) increases by a factor greater than 1 but less than 2

D) The answer depends on the value of the initial speed.

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Clicker Question

According to the relativistic expression for kinetic energy, the kinetic energy of an object of rest mass m_o moving with speed V

A) is equal to $(1/2)m_o V^2$

B) is less than $(1/2)m_o V^2$

C) is greater than $(1/2)m_o V^2$

D) depends on the value of the speed

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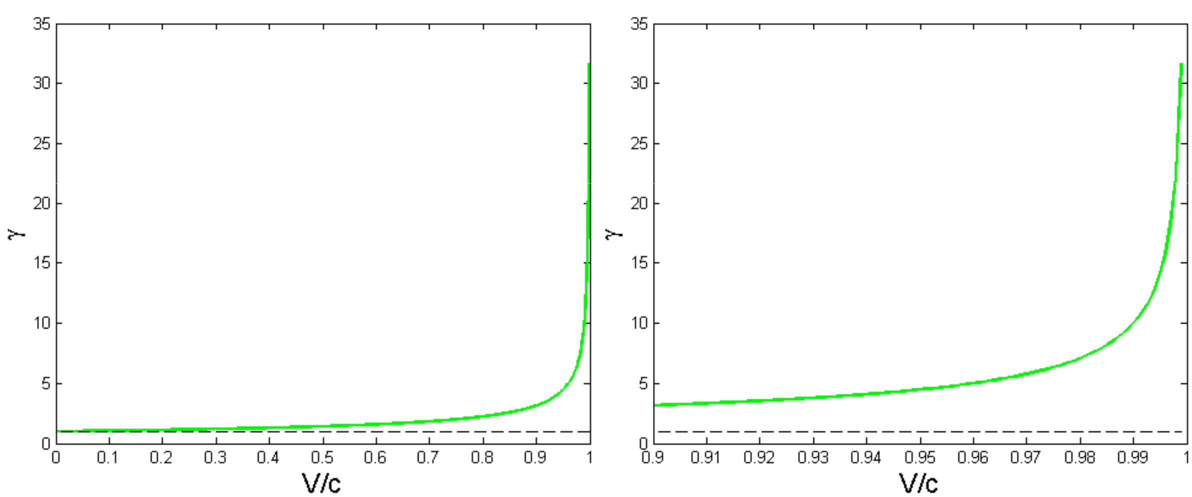
Lecture 27

$$\gamma = \frac{1}{\sqrt{1-\frac{V^2}{c^2}}}$$



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Clicker Question

If:

m_p = mass of proton
m_n = mass of neutron
m_e = mass of electron

What is the mass of a Helium atom ^4_2He?

A) less than $2m_p + 2\,m_n + 2\,m_e$

B) $2m_p + 2\,m_n + 2\,m_e$

C) more than $2m_p + 2\,m_n + 2\,m_e$

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Clicker Question

A particle at rest with rest mass 1116 MeV/c^2 decays to a proton with rest mass 938 MeV/c^2 and a pion with rest mass 140 MeV/c^2. What can you say about the (total) energy and momentum of the proton and pion?

A) The proton and pion have the same magnitude momentum and energy.

B) The proton and pion have the same energy but the proton has more momentum.

C) The proton and pion have the same momentum but the proton has more energy.

D) The proton and pion have equal and opposite momentum but the proton has more energy.

E) Give me a break, I just spent 8 hours doing a midterm

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Clicker Question

A student sees two lightning flashes and determines that one happens 10 ns before the other. Which statement is true:

A) Another inertial observer must find the order of events, the location of events, and the time difference to be the same.

B) Another inertial observer must find the order of events to be the same but the location and time difference may be different

C) Another inertial observer must find the order of events and the locations to be the same but the time difference may be different.

D) Any other inertial observer might find the order of events, the locations, and the time difference to be different.

E) Give me a break, I just spent 12 hours doing a midterm

Clicker Question

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A) Another inertial observer must find the order of events, the location of events, and the time difference to be the same.

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D) Any other inertial observer might find the order of events, the locations, and the time difference to be different.

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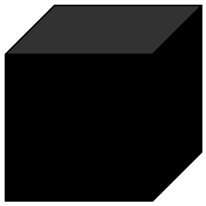
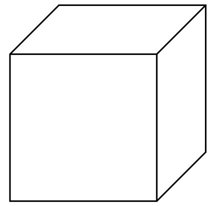
Clicker Question

Which object absorbs more light?



A)



B)

C) They absorb the same

Clicker Question

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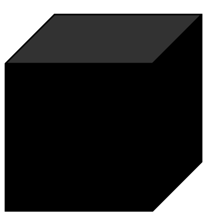
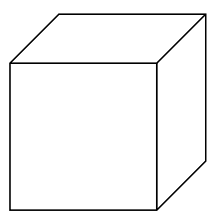


$\boxed{\text{A)}}$

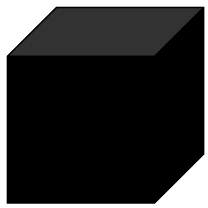


B)

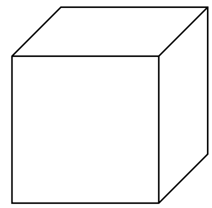
C) They absorb the same

Clicker Question

Which object emits more light in thermal equilibrium with the surroundings?



A)



B)

C) They emit the same

Clicker Question

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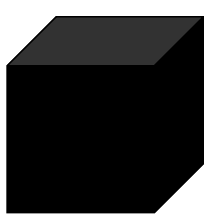
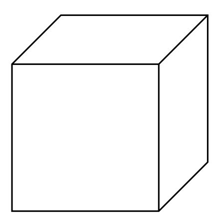


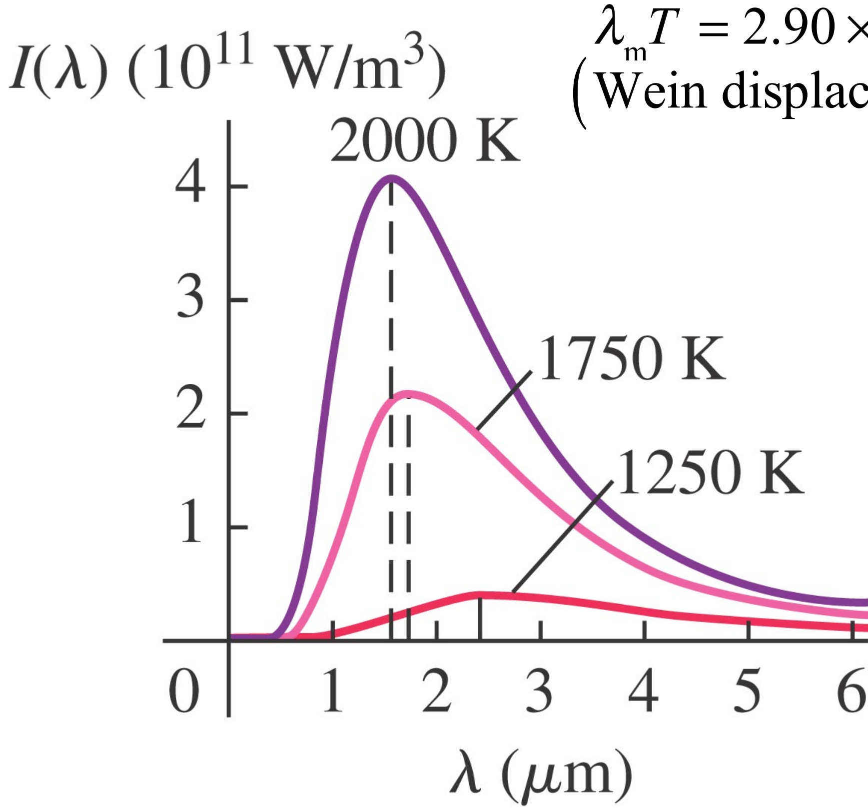
A)



B)

C) They emit the same

$$\lambda_m T = 2.90 \times 10^{-3}\ \text{m} \bullet \text{K}$$
(Wein displacement law)



Clicker Question

If you increase the temperature of a blackbody,

A) it emits more radiation at very short wavelengths and more radiation at very long wavelengths.

B) it emits more radiation at very short wavelengths but less radiation at very long wavelengths.

C) it emits less radiation at very short wavelengths but more radiation at very long wavelengths.

D) it emits less radiation at very short wavelengths and less radiation at very long wavelengths.

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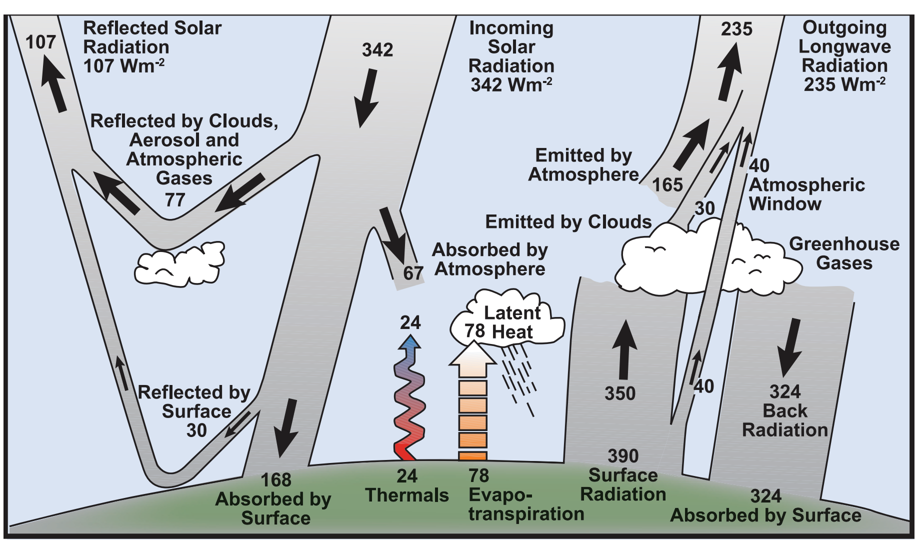
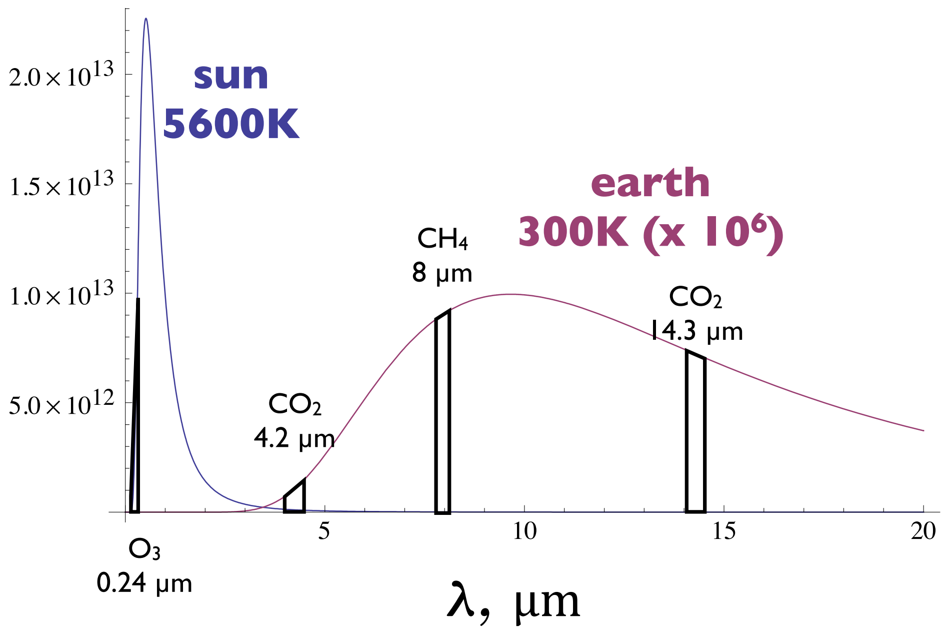
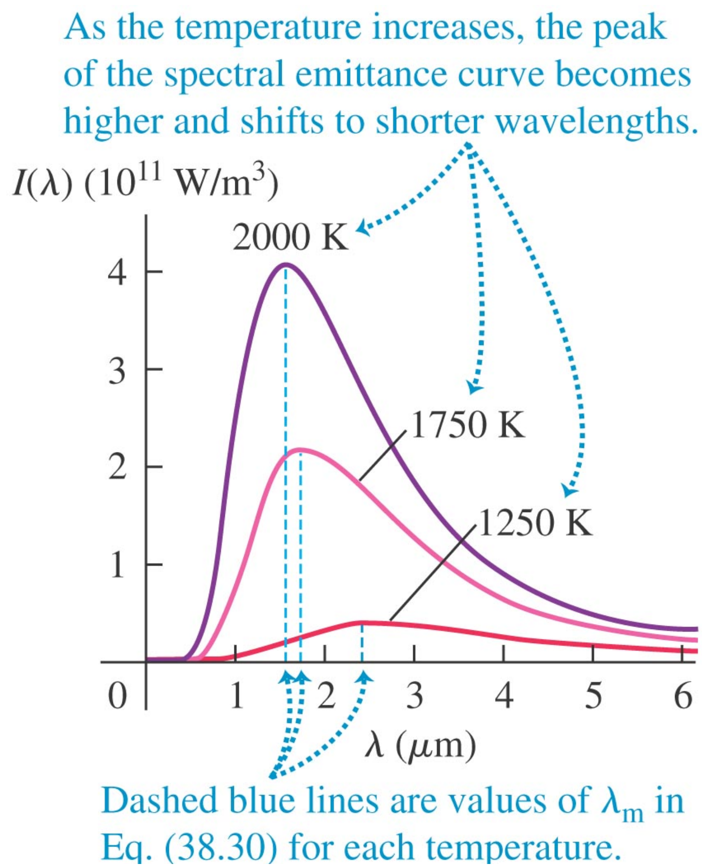



sun
5600K
earth
300K (x 10⁶)
2.0×10¹³
1.5×10¹³
1.0×10¹³
5.0×10¹²
CH₄
8 μm
CO₂
14.3 μm
CO₂
4.2 μm
O₃
0.24 μm
5
10
15
20
λ, μm



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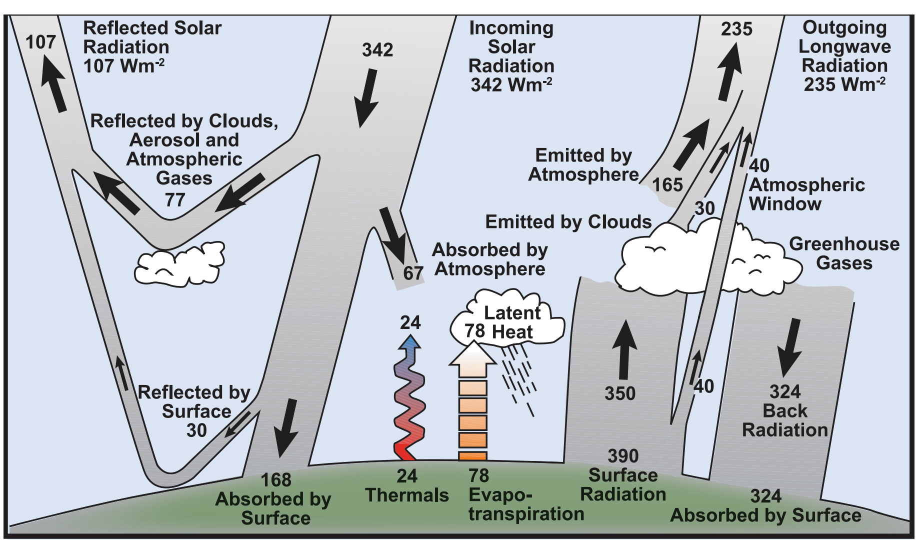

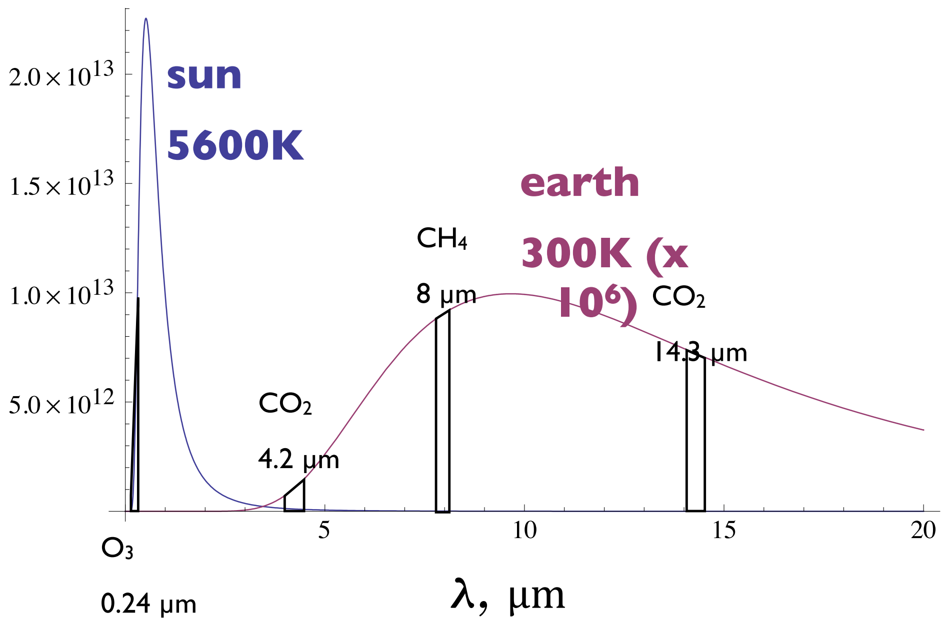

Clicker Question

In an experiment to demonstrate the photoelectric effect, you shine a beam of monochromatic blue light on a metal plate. As a result, electrons are emitted by the plate.
If you increase the intensity of the light but keep the color of the light the same, what happens?

A) More electrons are emitted per second.

B) The maximum kinetic energy of the emitted electrons increases.

C) both A. and B.

D) neither A. nor B.

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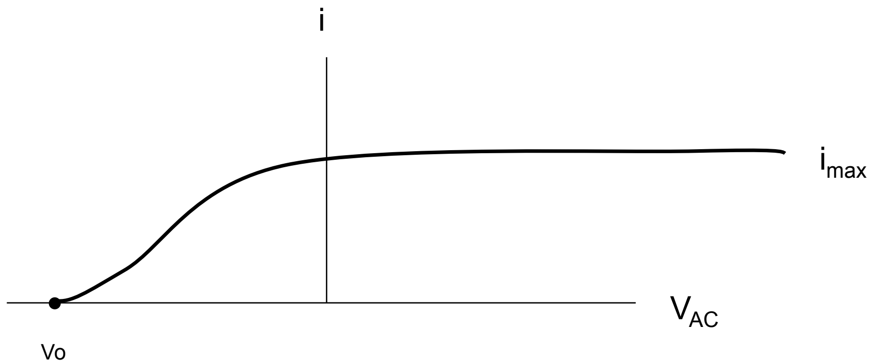


For the photo-electric effect data shown above, what is true about i_{max} and/or V_O when the intensity of light incident on the cathode is increased?

A) V_O moves left

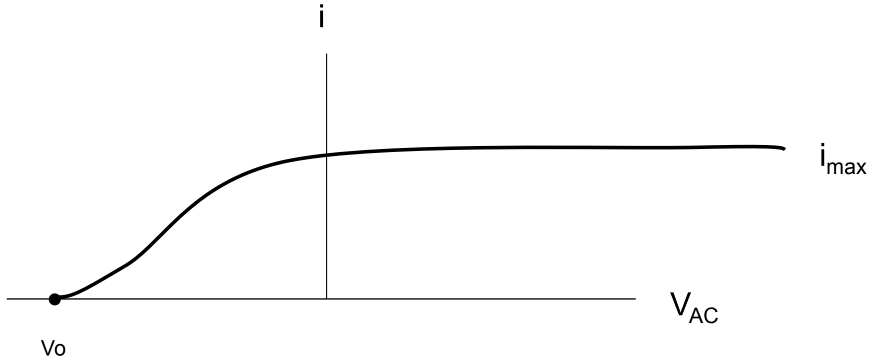
B) i_{max} increases

C) V_O moves right

D) A) and B)

E) B) and C)

Clicker Question



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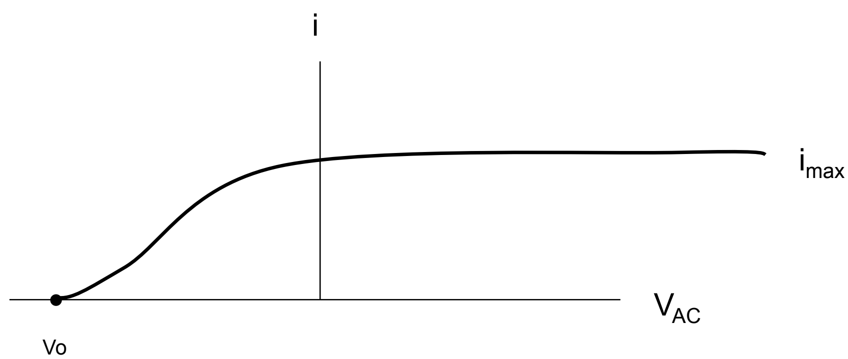

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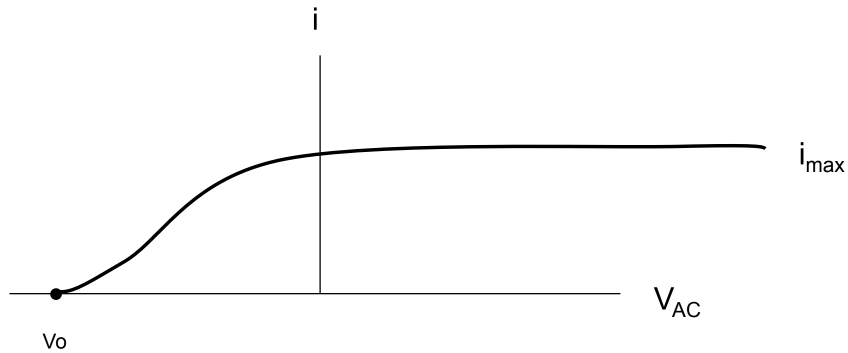
Clicker Question



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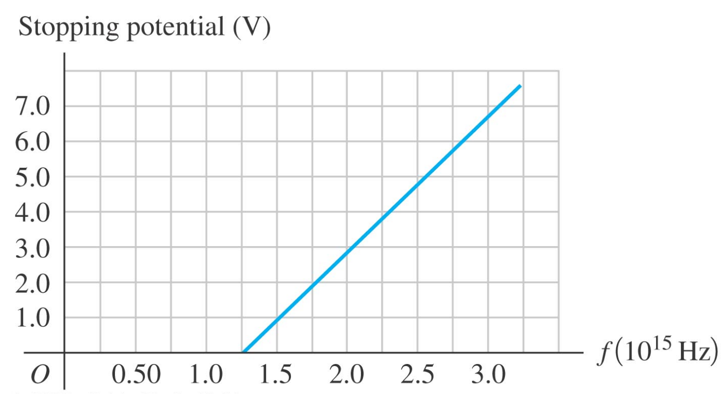
Clicker Question

This graph in shows the stopping potential as a function of the frequency of light falling on a metal surface. If a different type of metal is used,



A) the graph could have a different slope.

B) the graph could intercept the horizontal axis at a different value.

C) both A. and B.

D) neither A. nor B.

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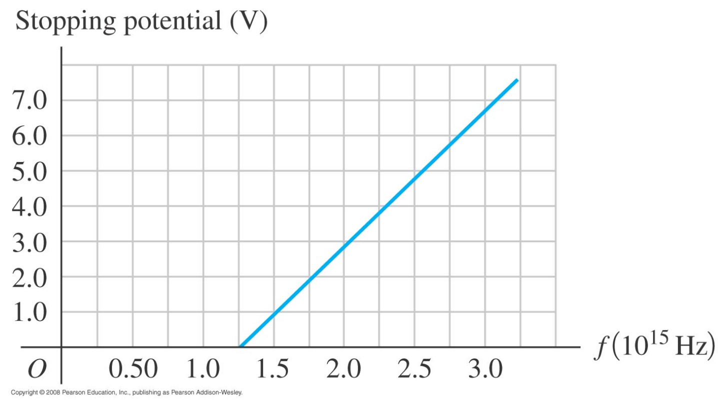

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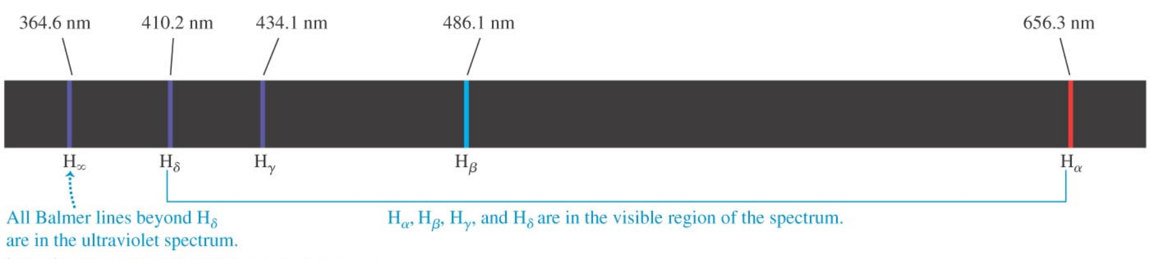
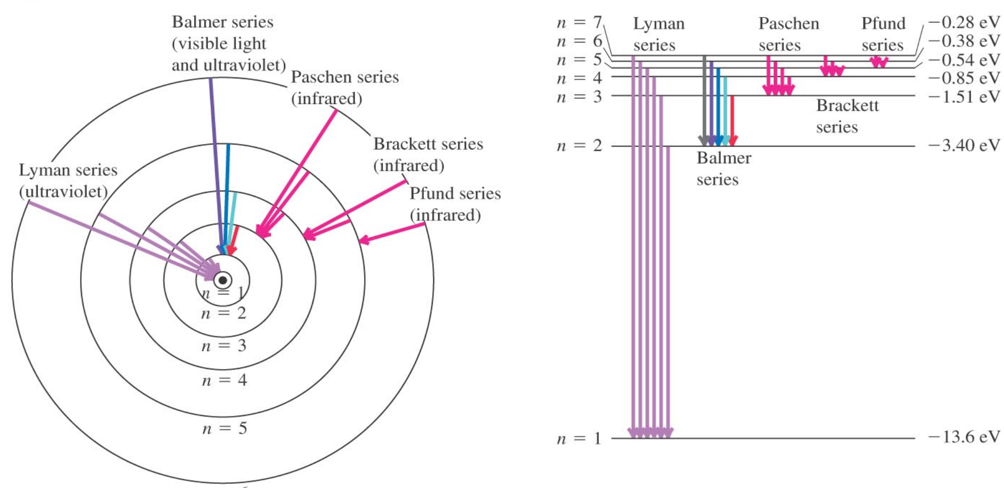


(a) "Permitted" orbits of an electron in the Bohr model of a hydrogen atom (not to scale). Arrows indicate the transitions responsible for some of the lines of various series.

(b) Energy-level diagram for hydrogen, showing some transitions corresponding to the various series



Clicker Question

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If you increase the intensity of the light but keep the color of the light the same, what happens?

A) More electrons are emitted per second.

B) The maximum kinetic energy of the emitted electrons increases.

C) both A. and B.

D) neither A. nor B.

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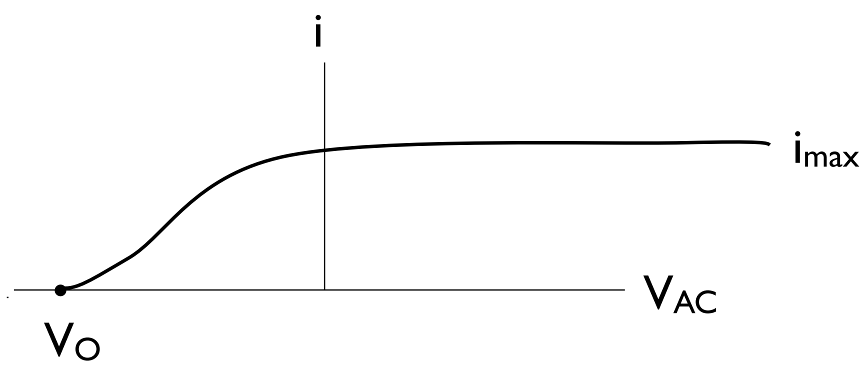


For the photo-electric effect data shown above, what is true about i_{max} and/or V_O when the intensity of light incident on the cathode is increased?

A) V_O moves left

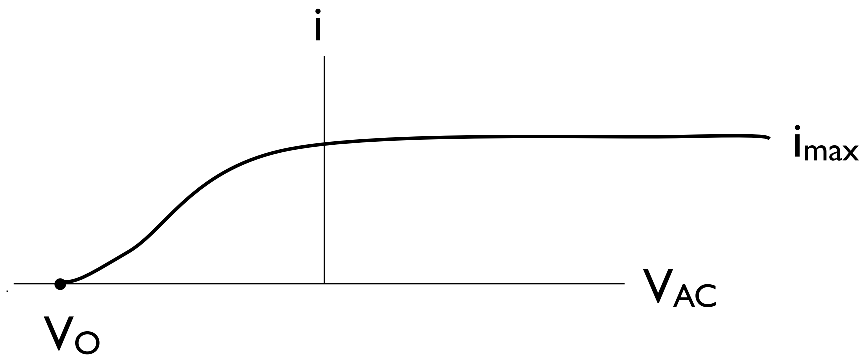
B) i_{max} increases

C) V_O moves right

D) A) and B)

E) B) and C)

Clicker Question



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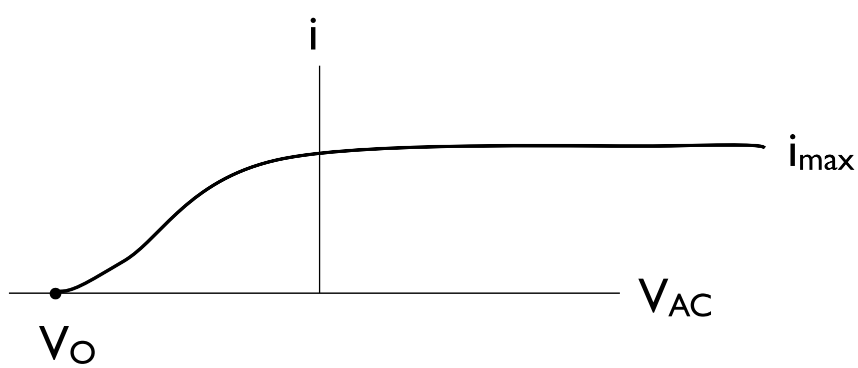

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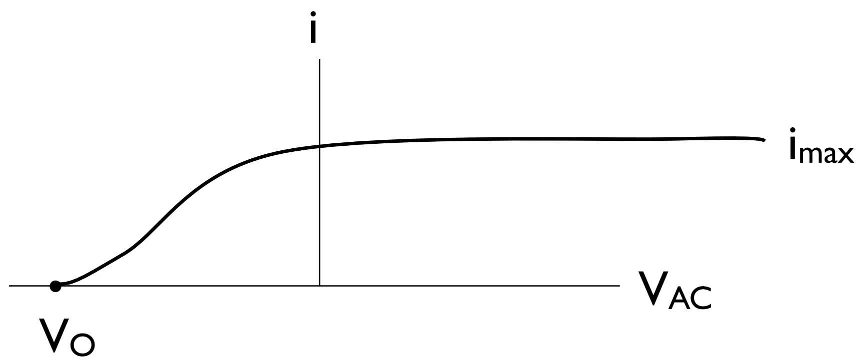

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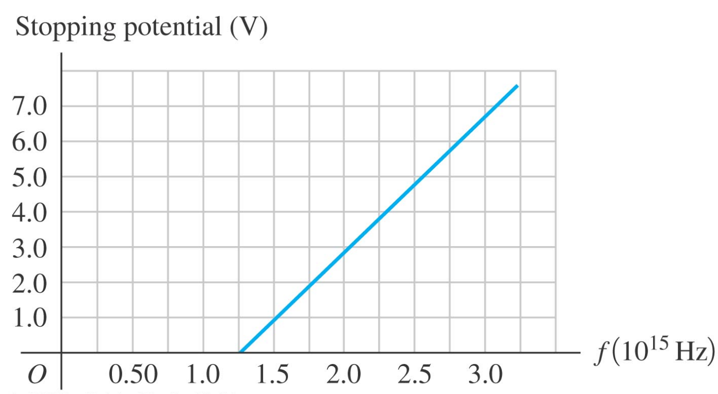
Clicker Question

This graph in shows the stopping potential as a function of the frequency of light falling on a metal surface. If a different type of metal is used,



A) the graph could have a different slope.

B) the graph could intercept the horizontal axis at a different value.

C) both A. and B.

D) neither A. nor B.

Clicker Question

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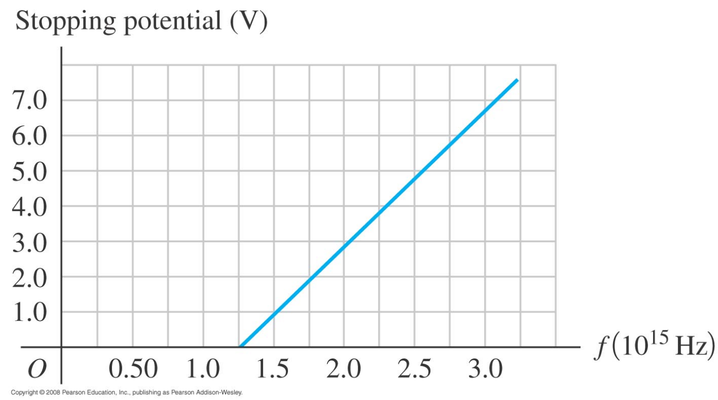

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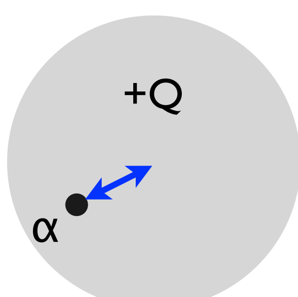
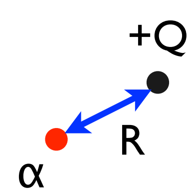
Clicker Question

Each sphere has total charge Q uniformly distributed throughout its volume. An alpha particle is located at a distance R from the center of each sphere. In which situation is a larger force acting on the alpha particle?

A)



B)



C) The forces are the same

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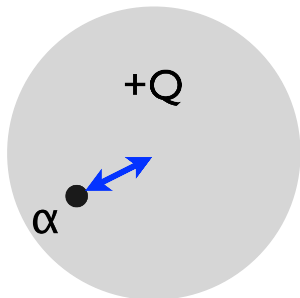
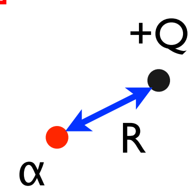


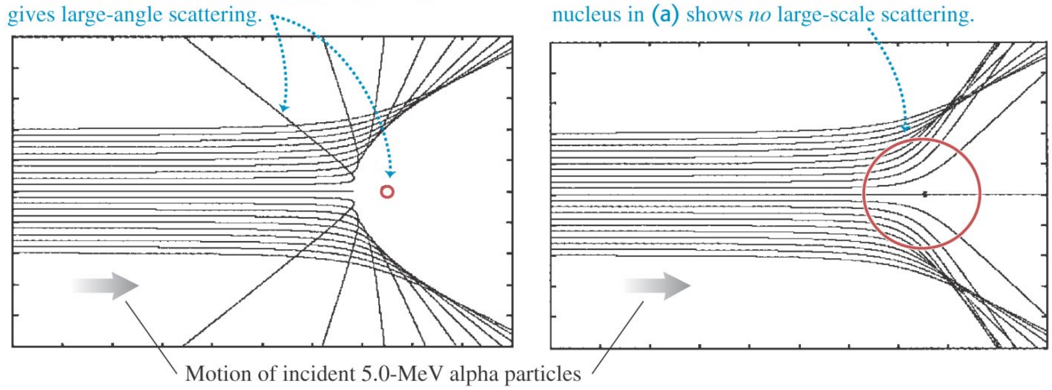
B)

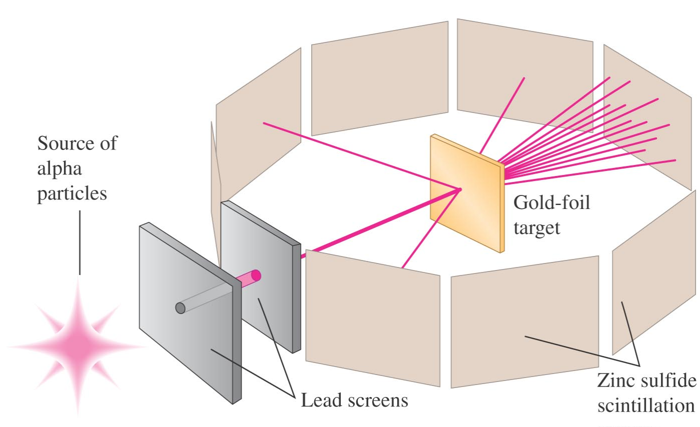


C) The forces are the same

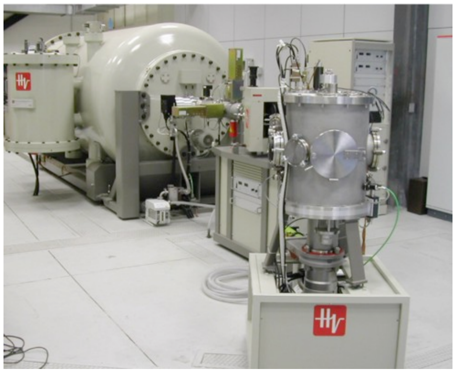
(a) A gold nucleus with radius 7.0×10^{-15} m gives large-angle scattering.

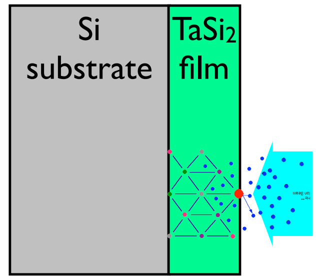
(b) A nucleus with 10 times the radius of the nucleus in **(a)** shows *no* large-scale scattering.

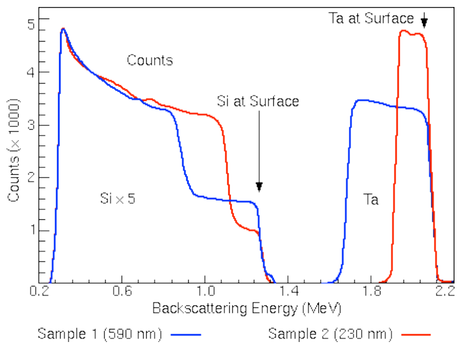


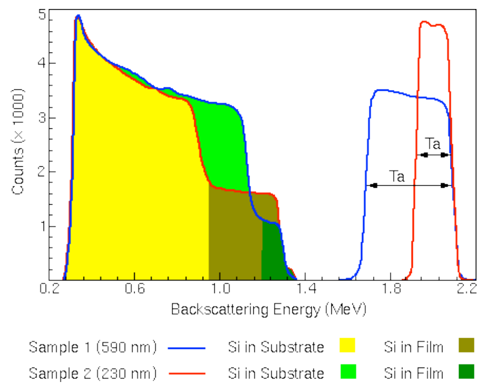


Rutherford Backscattering Spectroscopy

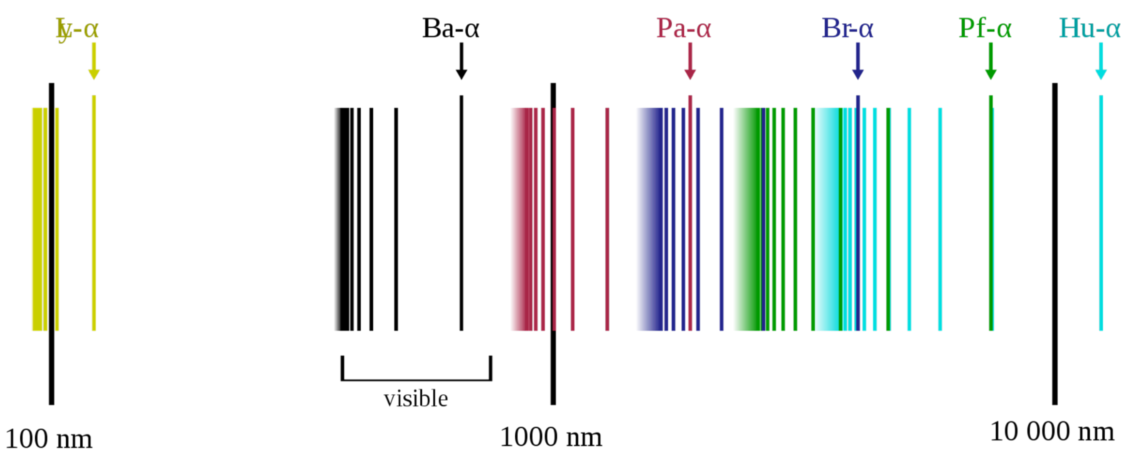


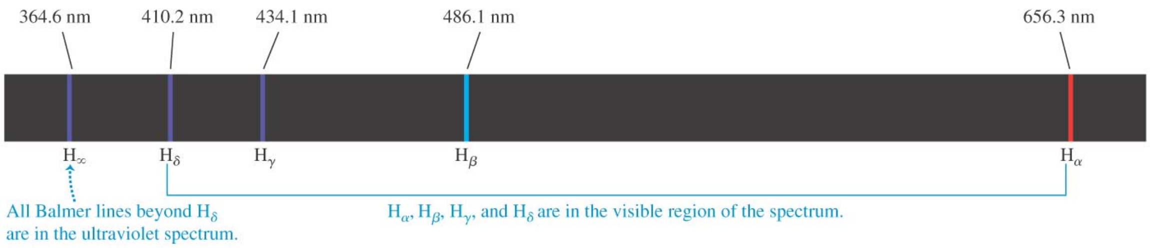






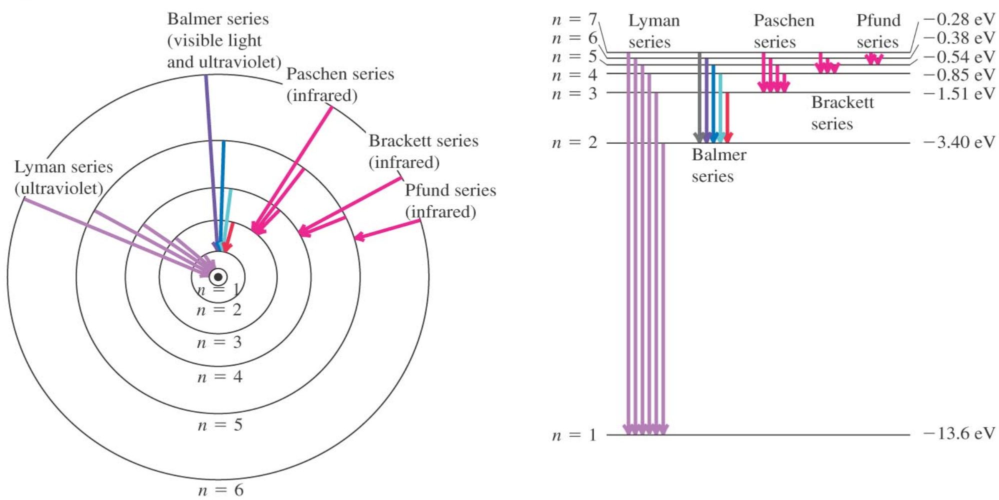
Complete Hydrogen Spectrum





(a) "Permitted" orbits of an electron in the Bohr model of a hydrogen atom (not to scale). Arrows indicate the transitions responsible for some of the lines of various series.

(b) Energy-level diagram for hydrogen, showing some transitions corresponding to the various series



Clicker Question

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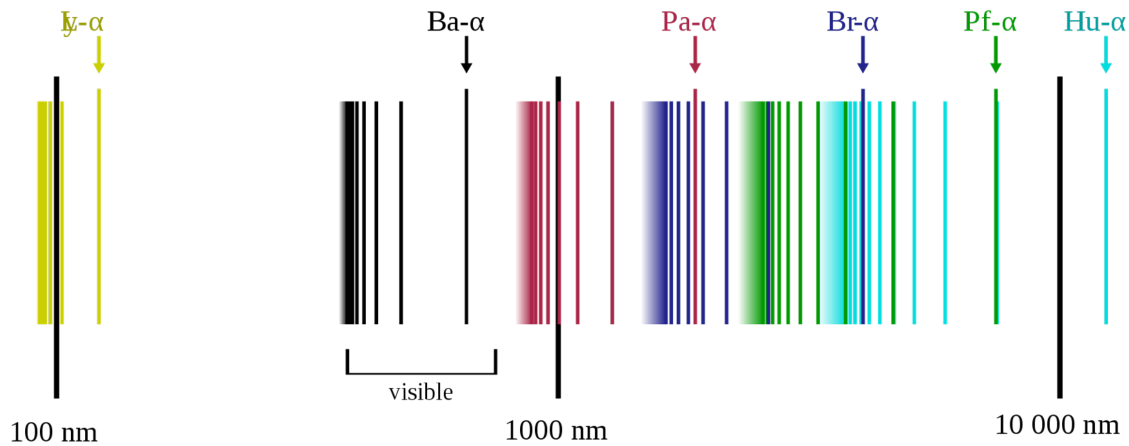

Hydrogen Levels

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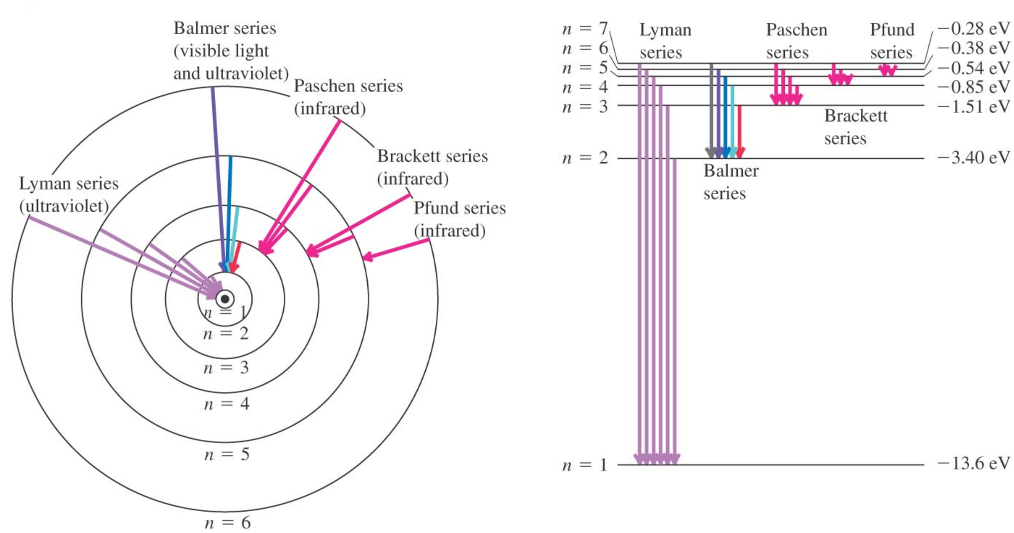

Clicker Question

In the Bohr model of the hydrogen atom, an electron in the n = 2 orbit has

A. a higher total energy and a higher kinetic energy than an electron in the n =1 orbit.

B. a lower total energy and a higher kinetic energy than an electron in the n =1 orbit.

C. a higher total energy and a lower kinetic energy than an electron in the n =1 orbit.

D. a lower total energy and a lower kinetic energy than an electron in the n =1 orbit.

E. none of the above

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E. none of the above

Clicker Question

A certain atom has two energy levels whose energies differ by 2.5 eV.

In order for a photon to excite an electron from the lower energy level to the upper energy level, what must be true about the energy of the photon?

A. Its energy must be greater than or equal to 2.5 eV.

B. Its energy must be exactly 2.5 eV.

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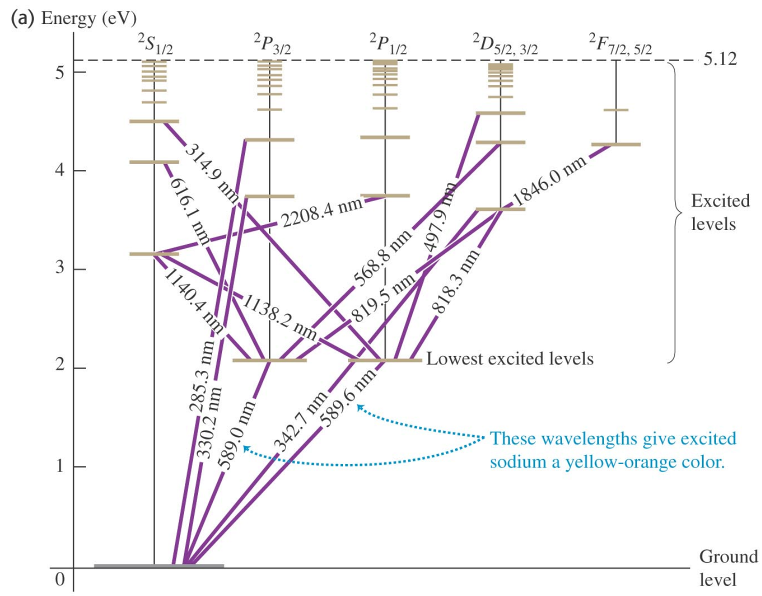
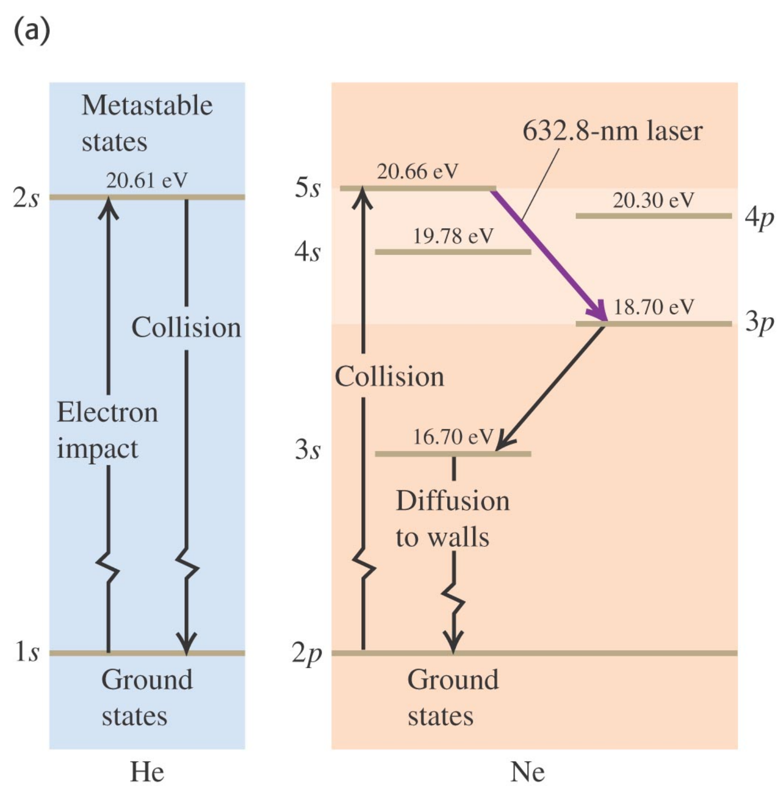
The Sodium Doublet

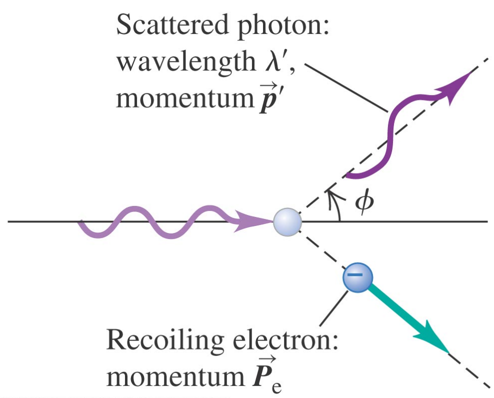


The Helium-Neon Laser

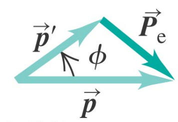


Compton Scattering

(b) After collision: The angle between the directions of the scattered photon and the incident photon is ϕ.



(c) Vector diagram showing the conservatio of momentum in the collision: $\vec{p} = \vec{p}' + \vec{P}_e$



Clicker Question

When an x-ray photon bounces off an electron,

A. the photon wavelength decreases
and the photon frequency decreases.

B. the photon wavelength decreases
and the photon frequency increases.

C. the photon wavelength increases
and the photon frequency decreases.

D. the photon wavelength increases and
the photon frequency increases.

E. none of the above

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1861 -Maxwell's Equations
1885 -Balmer finds formula for visible Hydrogen spectral lines.
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1926 -Schrödinger equation
1927 -Davisson-Germer electron diffraction

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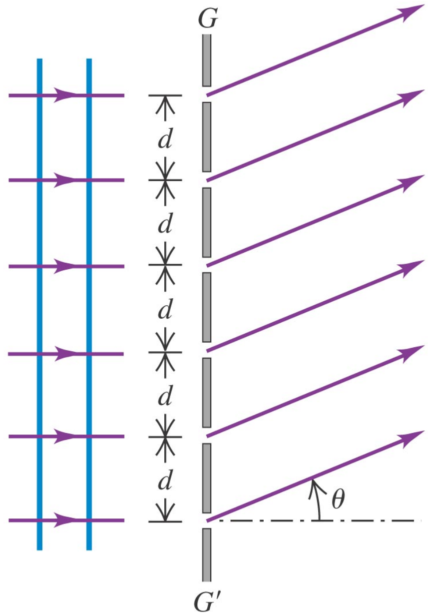
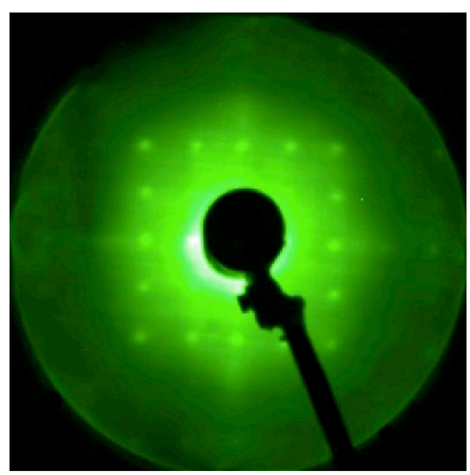
$$d\sin\theta = m\lambda \qquad (m = 0, \pm 1, \pm 2, \pm 3, \ldots) \qquad \text{(intensity maxima, multiple slits)} \qquad (36.13)$$



Clicker Question

In the electron diffraction experiment, if we increase the voltage by which the electrons are accelerated:

a) The diffraction pattern features will get farther apart.
b) The diffraction pattern features will get closer together.
c) The diffraction pattern features will stay the same.



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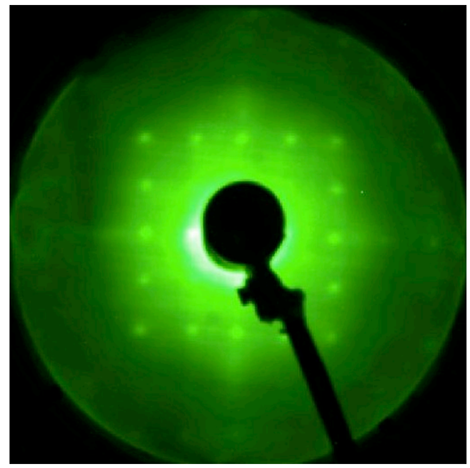


Figure 39.6

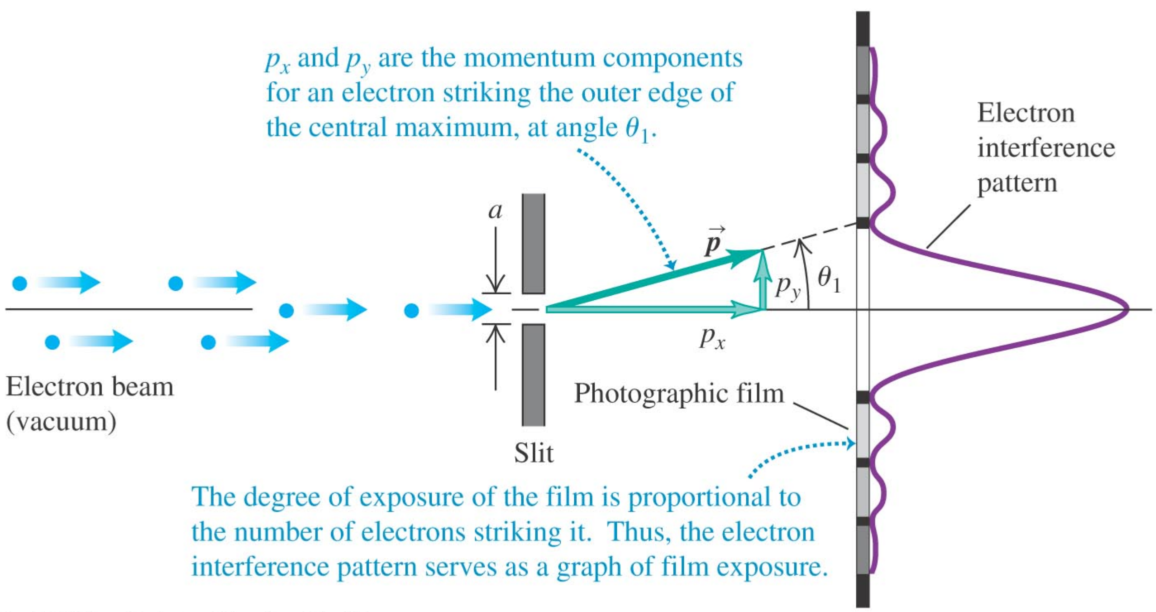
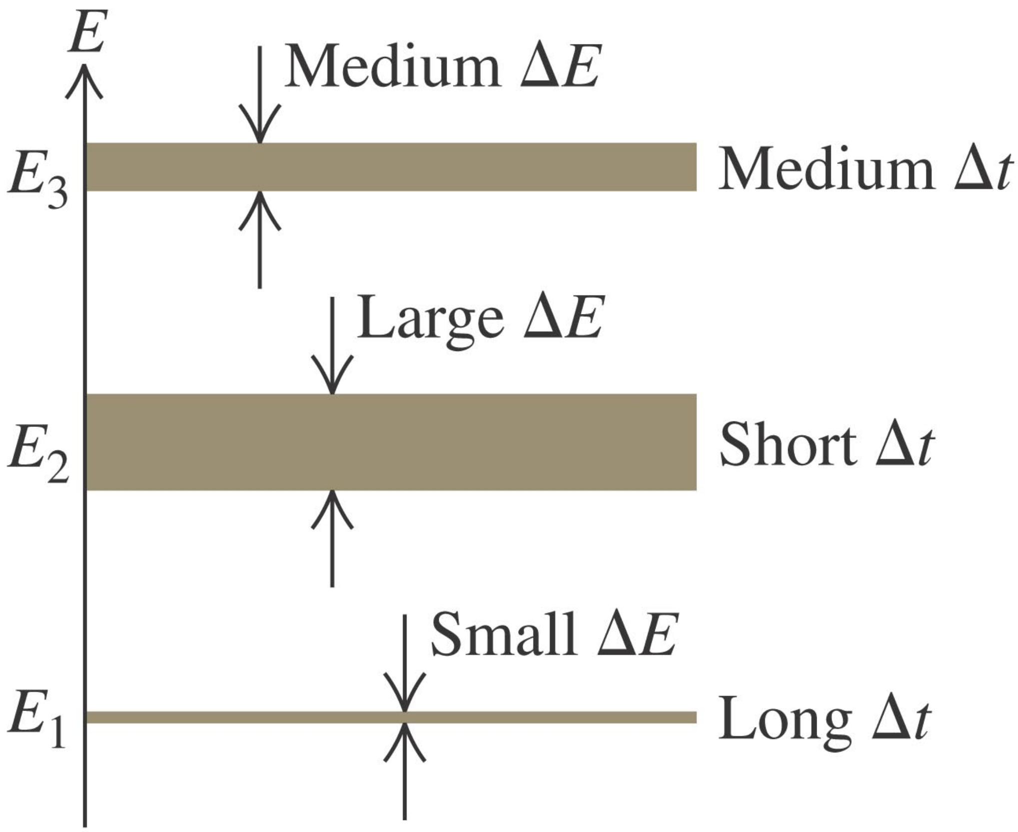
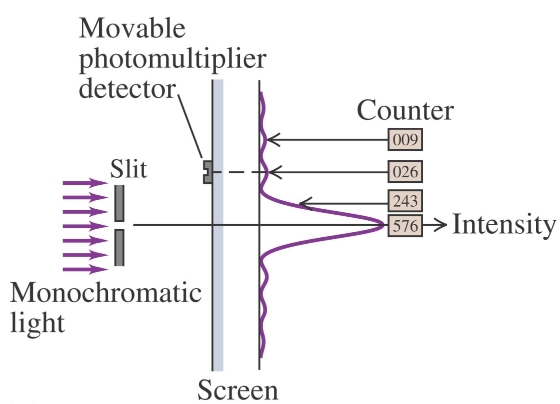


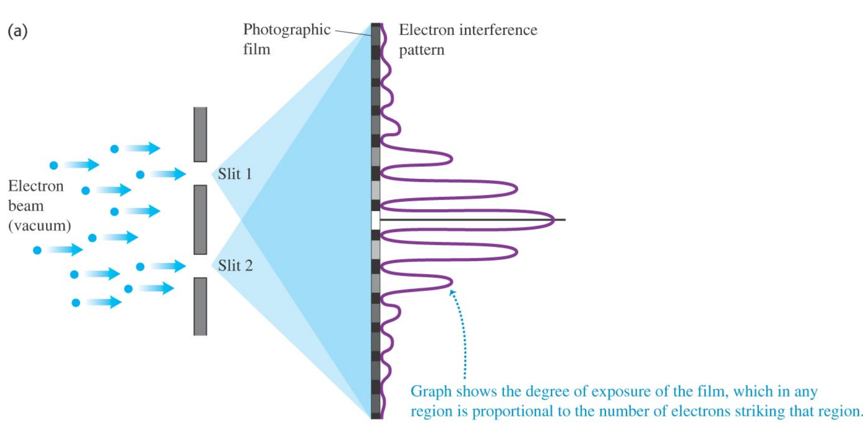
Figure 39.8



E
Medium ΔE
E_3
Medium Δt
Large ΔE
E_2
Short Δt
Small ΔE
E_1
Long Δt

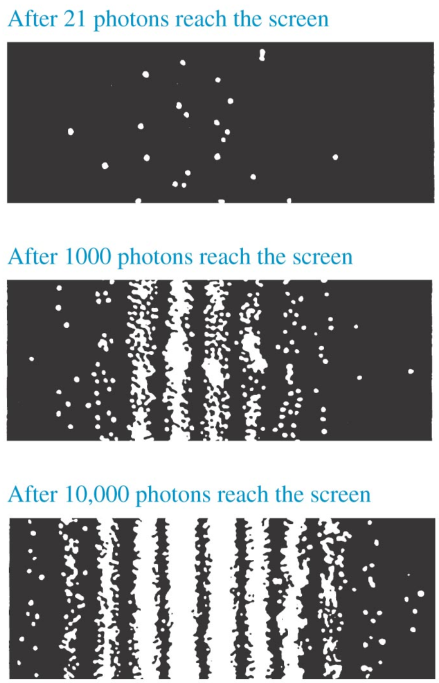


Movable photomultiplier detector
Counter
009
026
243
576
Intensity
Slit
Monochromatic light
Screen

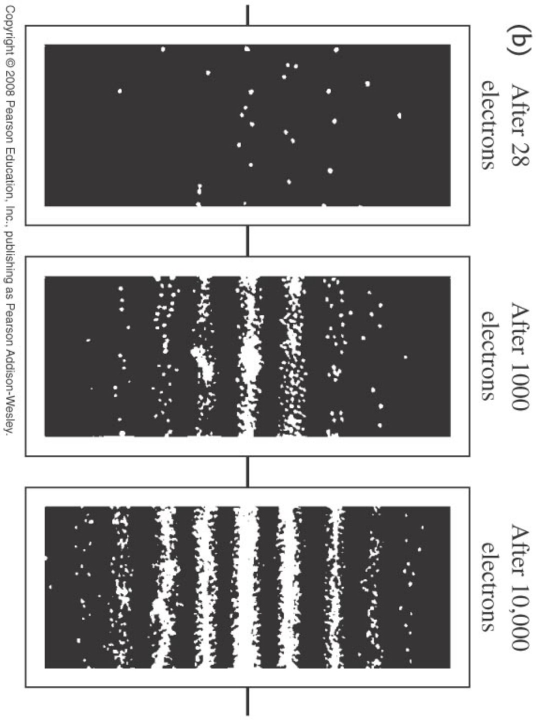


(a)
Photographic film
Electron interference pattern
Electron beam (vacuum)
Slit 1
Slit 2
Graph shows the degree of exposure of the film, which in any region is proportional to the number of electrons striking that region.

Photons



Electrons



Clicker Question

An electron is free to move anywhere within a cube of copper 1 cm on a side. Compared to an electron within a hydrogen atom, the electron in copper

A. has a much smaller uncertainty in momentum.

B. has a slightly smaller uncertainty in momentum.

C. has the same uncertainty in momentum.

D. has a slightly larger uncertainty in momentum.

E. has a much larger uncertainty in momentum.

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Clicker Question

For a free particle with momentum p, the wave is a function is

$$\psi(x,t) = A\exp(ikx)\exp(-i\omega t)$$

Where is the particle most likely to be found?

A) x=0

B) It depends on t

C) Can't be calculated with just the above information.

D) Is equally likely to be found anywhere

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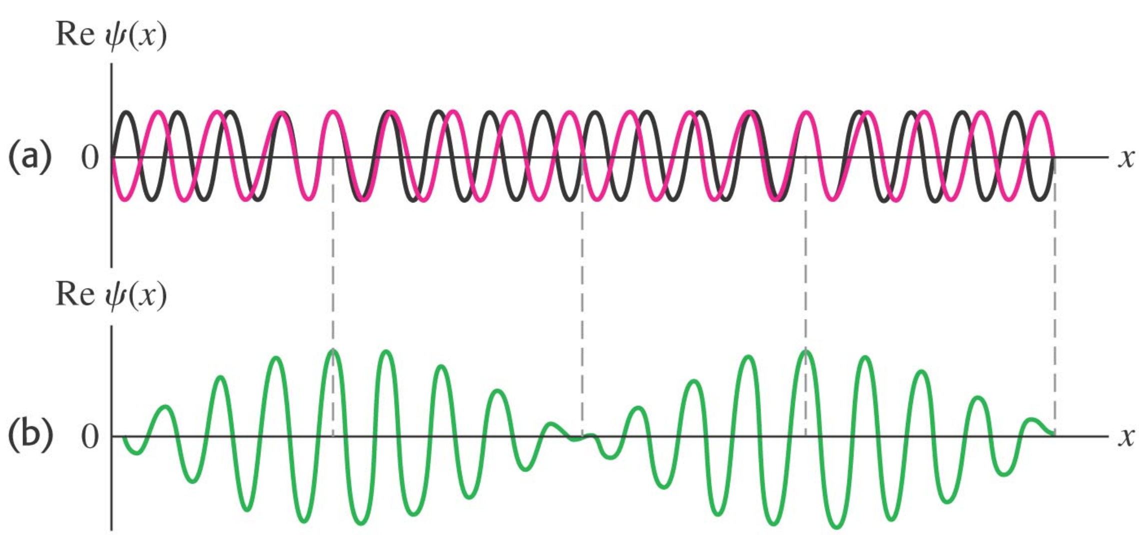
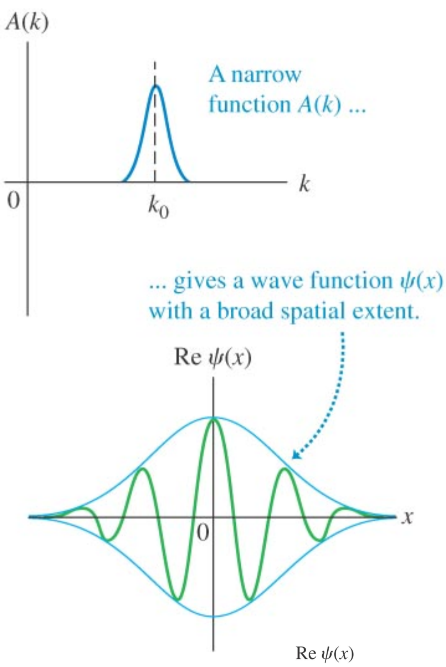
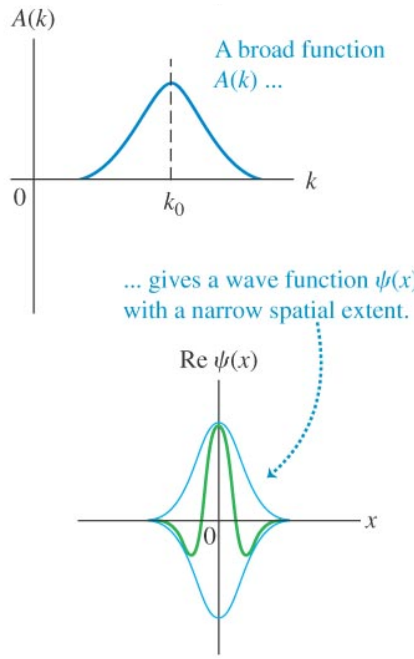
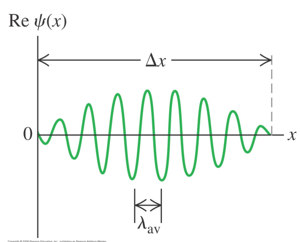
More than one plane wave begins to define a WAVEPACKET









How does Δp behave in these examples?

Clicker Question

The free particle solution to the Schrödinger equation is

$$\Psi\left(x,t\right) = A\,e^{ikx}e^{-i\frac{E\,t}{\hbar}}$$

Which value of k would you expect to correspond to the fastest moving wave fronts? E is the same in all.

a) $k = 1.75\ \mathrm{m}^{-1}$

b) $k = 2\ \mathrm{m}^{-1}$

c) $k = 2.25\ \mathrm{m}^{-1}$

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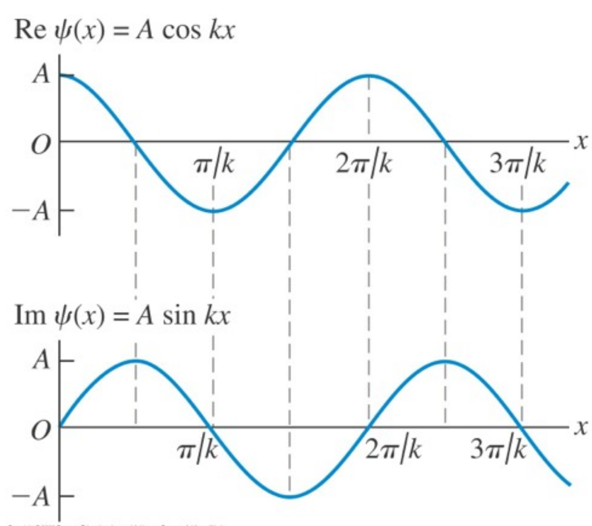
Clicker Question

The graph shows the real and imaginary parts of a particular wave function for a free particle. At which value(s) of x is there zero probability of finding the particle?



A) x = 0

B) x = π/2k

C) x = π/k

D) x = 3π/2k

E) none of these

Clicker Question

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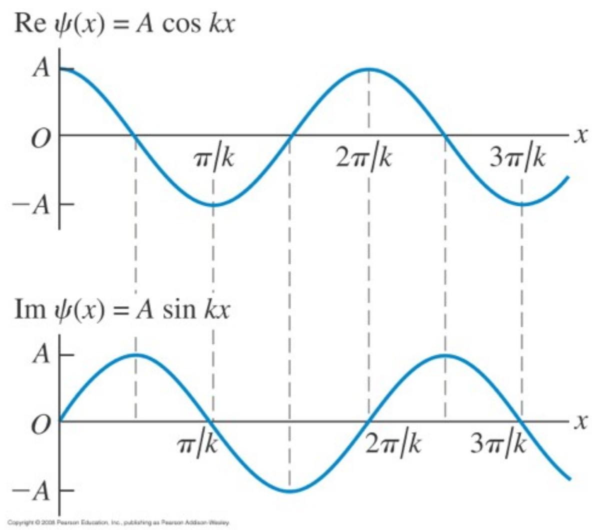

A) $x = 0$

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D) $x = 3\pi/2k$

$\boxed{\text{E) none of these}}$

Clicker Question

The free particle solution to the Schrödinger equation is

$$\Psi(x,t) = A e^{ikx} e^{-i\frac{E\,t}{\hbar}}$$

If the energy *E* is the same, for which of the following values of *k* would you expect the time evolution of the wavefunction to show the fastest moving phase fronts?

A) $k = 1.75\ \mathrm{m}^{-1}$

B) $k = 2\ \mathrm{m}^{-1}$

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D) The time evolution of the phase fronts is the same for all cases

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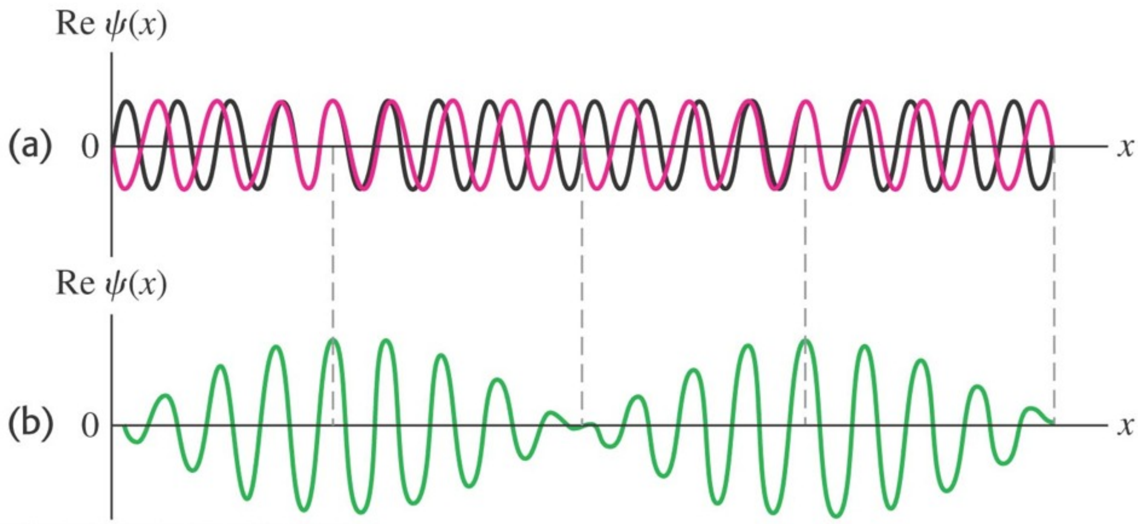
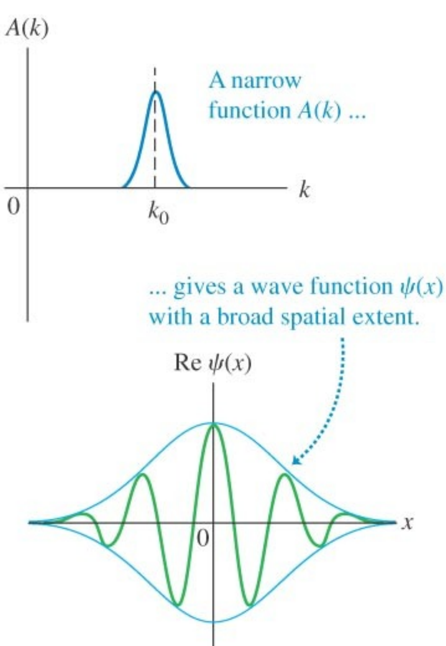
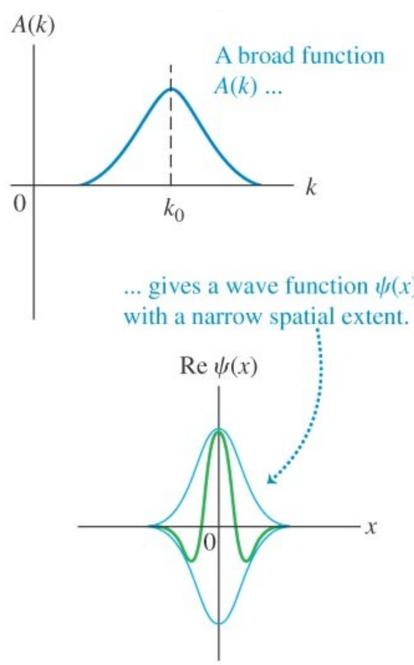
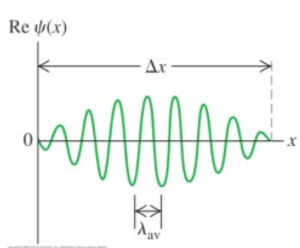




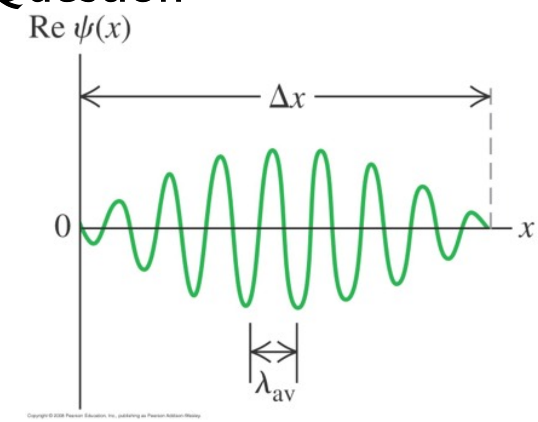




How does Δp behave in these examples?

Clicker Question

The graph shows the real part of a particular wave function for a free particle. The quantum-mechanical state represented by this wave function



A) has definite momentum and definite energy.

B) has definite momentum, but not definite energy.

C) has definite energy, but not definite momentum.

D) has neither definite energy nor definite momentum.

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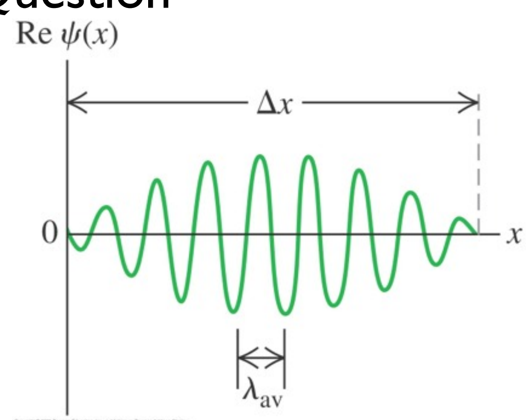

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Clicker Question

An electron is free to move anywhere within a cube of copper 1 cm on a side. Compared to an electron within a hydrogen atom, the electron in copper

A) has a much smaller uncertainty in momentum.

B) has a slightly smaller uncertainty in momentum.

C) has the same uncertainty in momentum

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Lecture 39

http://phet.colorado.edu/en/simulation/quantum-tunneling

Clicker Question

The first five wave functions for a particle in a box are shown.

The probability of finding the particle near x = L/2 is

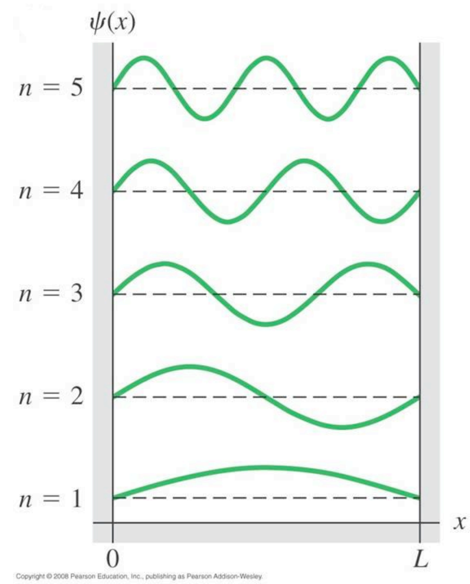
A) least for n = 1.

B) least for n = 2 and n = 4.

C) least for n = 5.

D) the same (and nonzero) for n = 1, 2, 3, 4, and 5.

E) zero for n = 1, 2, 3, 4, and 5.



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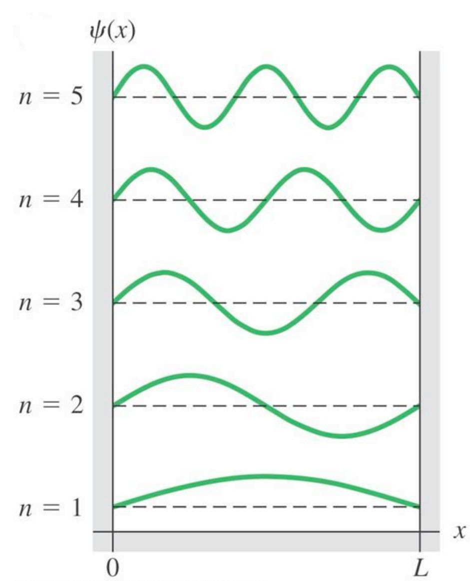


Clicker Question

The first five wave functions for a particle in a box are shown. Consider the wavefucntions for n=1 and n=5.

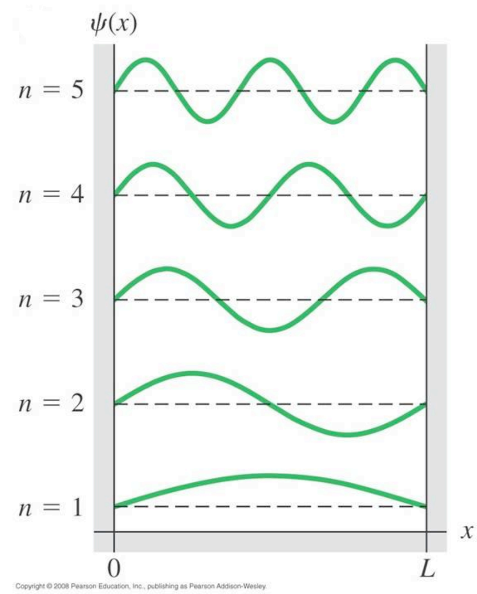
The average value of the x-component of momentum is

A) least for n = 1.

B) least for n = 5.

C) the same (and nonzero) for n = 1 and n = 5.

D) zero for both n = 1 and n = 5.



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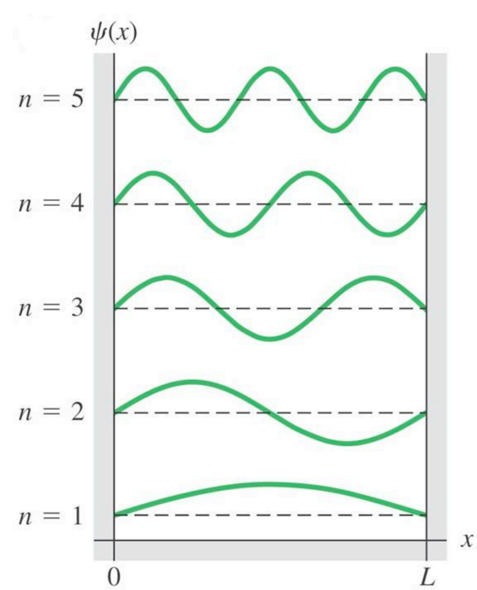
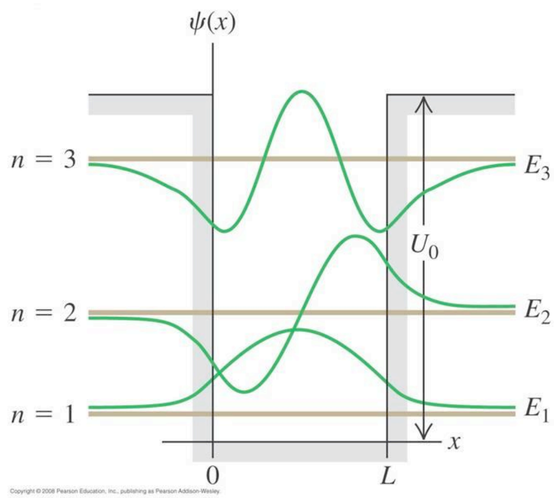


Clicker Question

The first three wave functions for a finite square well are shown. The probability of finding the particle at $x > L$ is



A) least for n = 1.

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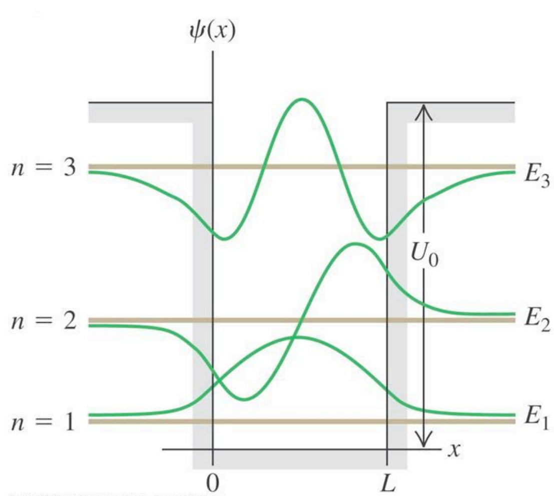

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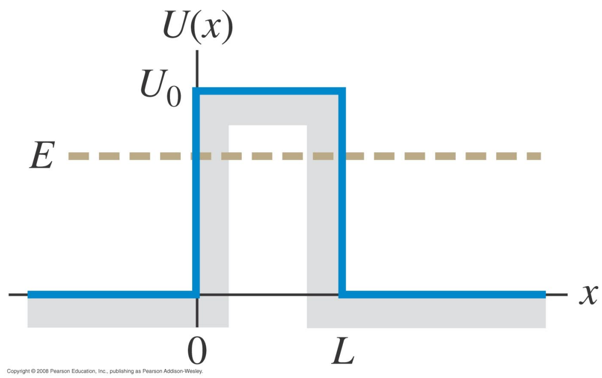
A potential-energy function is shown. If a quantum-mechanical particle has energy $E < U_0$, it is *impossible* to find the particle in the region



A) $x < 0$.

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D) misleading question — the particle can be found at any x

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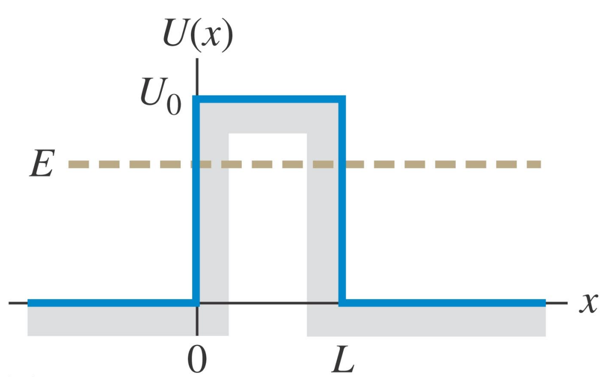

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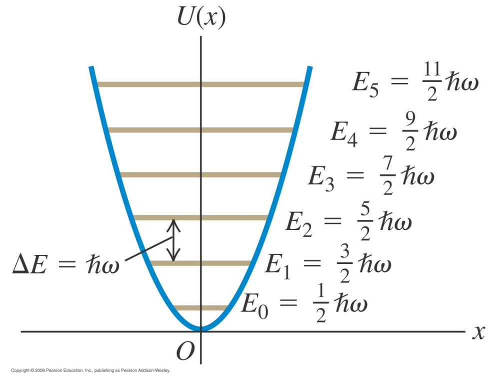


The figure shows the first six energy levels of a quantum-mechanical harmonic oscillator. The corresponding wave functions

A) are nonzero outside the region allowed by Newtonian mechanics.

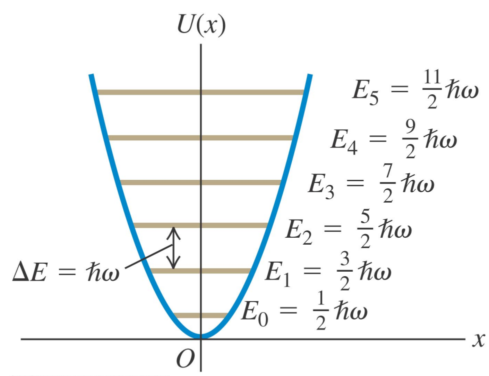
B) do not have a definite wavelength.

C) are all equal to zero at x = 0.

D) Both A and B are true.

E) All of A, B, and C are true.

Clicker Question



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Which of the following statements are true about a quantum mechanical wavefunction that is a plane wave?

(I) the wavefunction is normalizable.
(II) the wavefunction is a solution of the free-particle (U(x) =0) Schrödinger equation.
(III) the wavefunction is a state with a definite momentum.

A) None of them
B) I and II
C) I and III
D) II and III
E) All of them

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Lecture 41

http://phet.colorado.edu/en/simulation/quantum-tunneling

http://phet.colorado.edu/en/simulation/bound-states

Clicker Question

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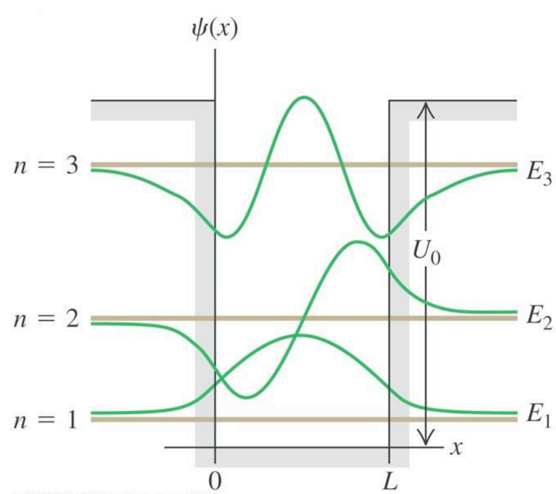

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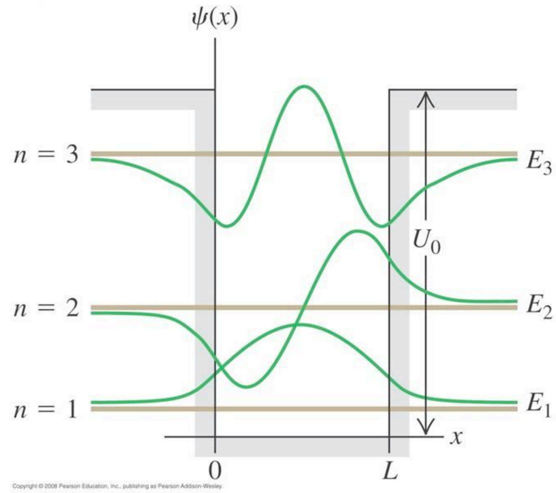

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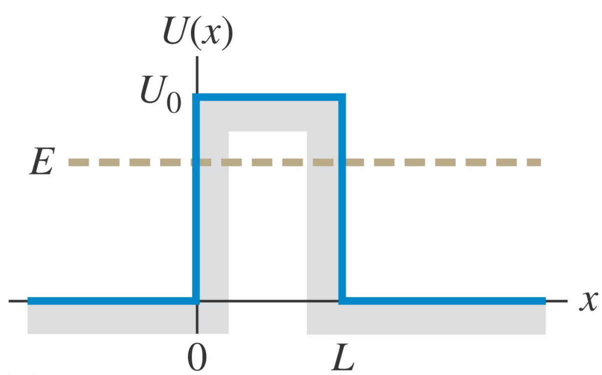

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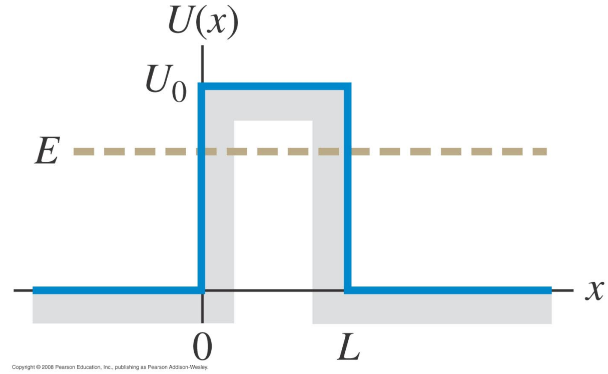

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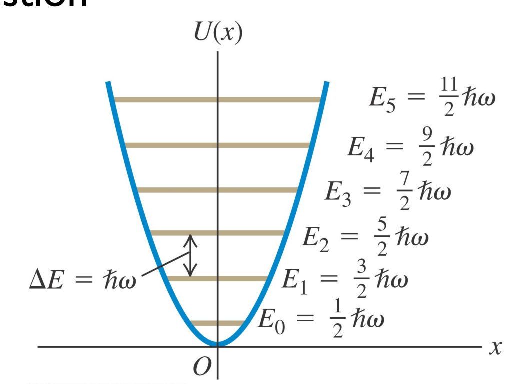

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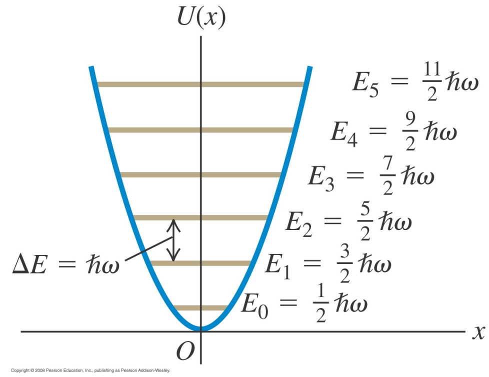

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Lecture 41

http://phet.colorado.edu/en/simulation/quantum-tunneling

http://phet.colorado.edu/en/simulation/bound-states

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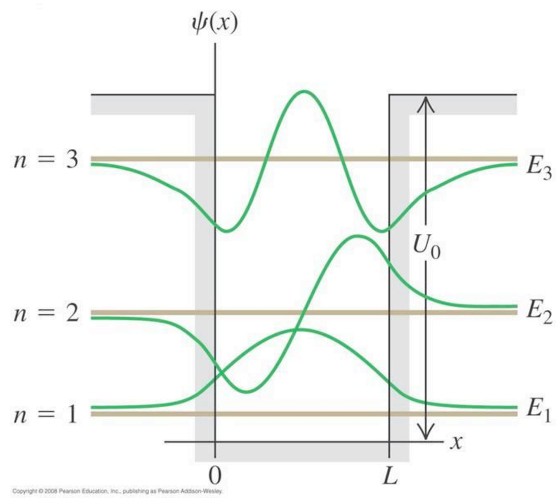

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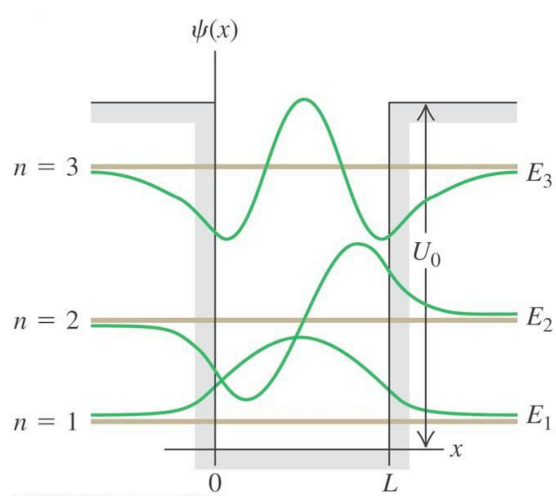

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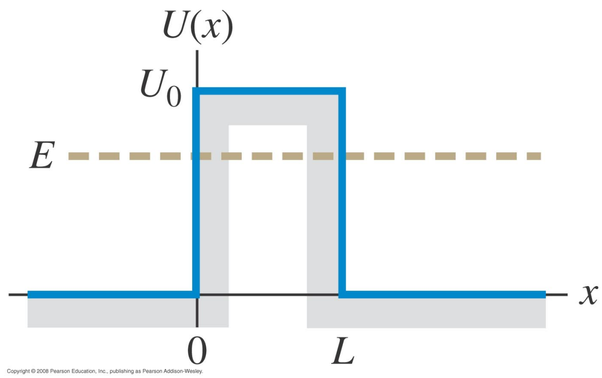

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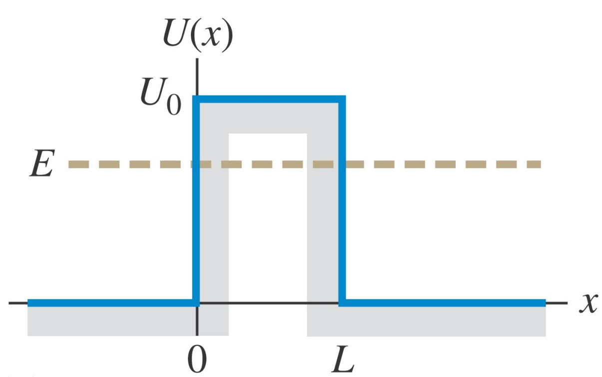

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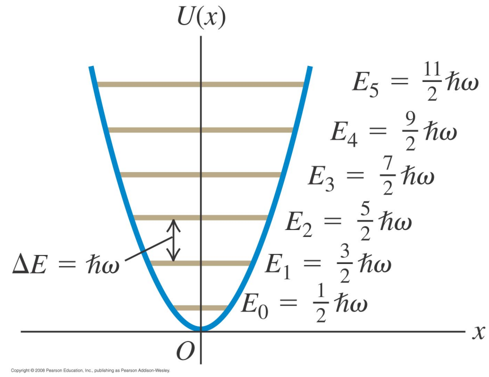

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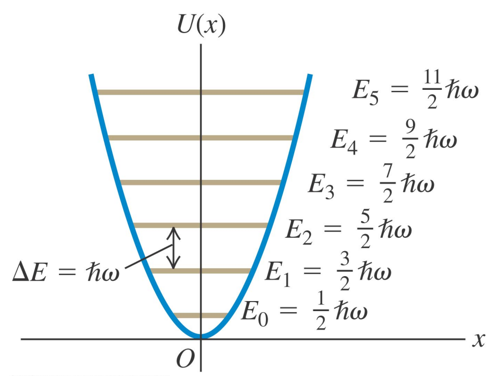

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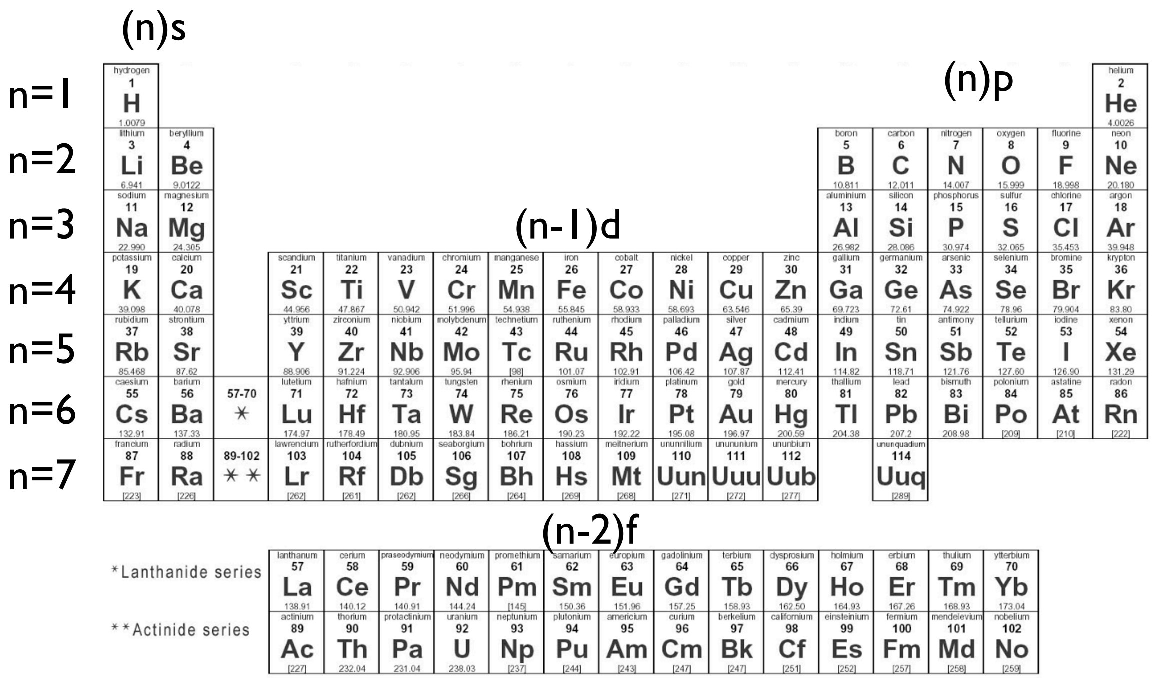
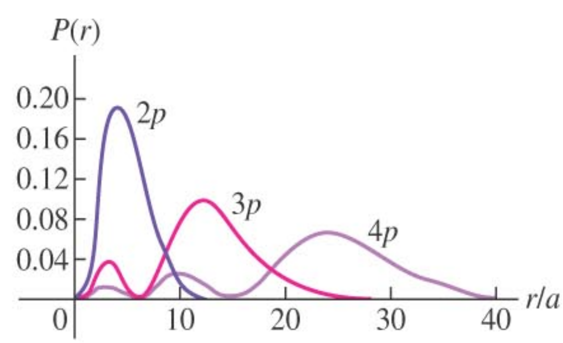


Clicker Question

This illustration shows radial probability distribution functions for three hydrogen-atom wave functions, plotted versus r/a (r = distance from the center of the atom and a = 0.0529 nm). It follows that



A) an electron in a 4p state is always farther from the center of the atom than is an electron in a 2p state.

B) an electron in a 2p state can be found at the atom's center.

C) a 3p state has 3 units of orbital angular momentum.

D) none of the above is true.

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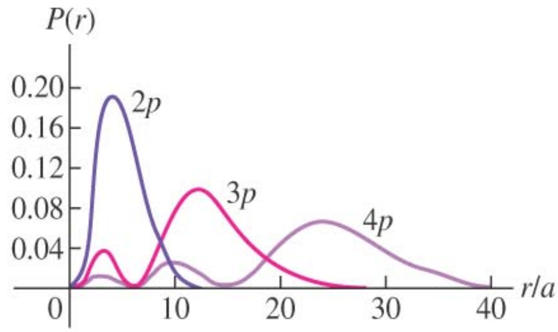

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