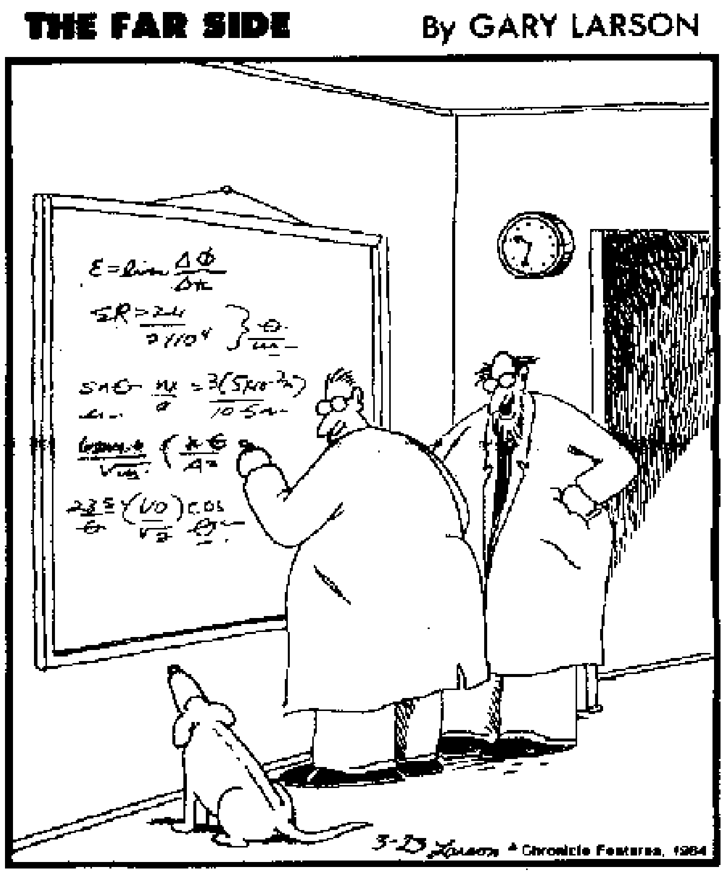
Modern Physics



"Ohhhhhhh . . . Look at that, Schuster . . . Dogs are so cute when they try to comprehend quantum mechanics."

Modern Physics

- Classical Physics (pre 1900's):
  - Newtonian mechanics
    - Deterministic
    - small velocities large distances

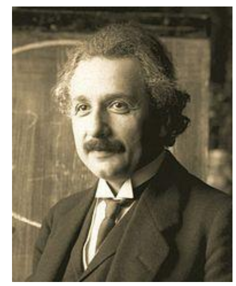
(same output, not random)

PARADIGM SHIFT

(a dramatic change in methodology or practice)

- Modern Physics (1900's – Present):
  - Special Relativity: very fast
  - General Relativity: very large (massive) – gravity
  - Quantum Mechanics: very small

The Dual Nature of Light



Historically, light has sometimes been viewed as a particle rather than a wave; Newton, for example, thought of light this way. The particle view was pretty much discredited with Young's double slit experiment, which made things look as though light had to be a wave. But in the early 20th century, some physicists (Einstein, for one) began to examine the particle view of light again.

What proof exists that light is a wave?

- Diffraction
- Interference
- Doppler Effect
- Polarization

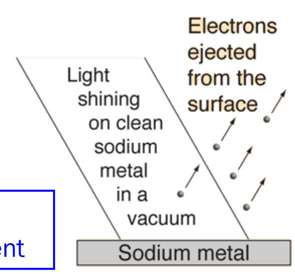
Classical Theory says . . . light acts as a wave and the energy of a wave depends on its amplitude (intensity) not its frequency.

DEMO – zinc (newly cleaned w/ steel wool), uv light source, electroscope; place zinc on electroscope, charge electroscope negative, shine uv light on zinc which will discharge scope.

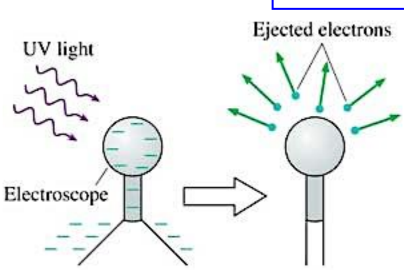
The Photoelectric Effect

Discovered by Heinrich Hertz in 1887

- The Photoelectric Effect – the emission of electrons from a metal when electromagnetic radiation of high enough frequency (or low enough wavelength) falls on the surface.
  - practical application: solar cells, CCD cameras



DEMO – Photocell – connect the ammeter to the photocell, shine a regular light bulb onto the photocell and the ammeter shows the current



Ultraviolet light discharges a negatively charged electroscope by causing it to emit electrons.

The Experiment

1. Light of varying frequencies and intensities are shone on a metal surface (photoemissive surface).
2. Light below a certain frequency will not emit electrons (photo-electrons) no matter how intense it is or how long it shines on the surface. Light at or above a certain frequency will immediately emit electrons no matter how intense it is.

- Threshold frequency (f_o) – minimum frequency of light needed to eject electrons from the surface of the metal.

Einstein noted that careful experiments involving the photoelectric effect could show whether light consists of particles or waves.

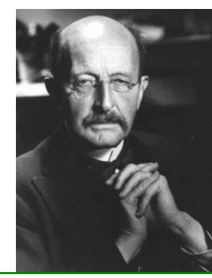
	Classical predictions	Experimental evidence
Whether electrons are ejected or not depends on . . .	Intensity of the light (If intense enough, electrons will be ejected no matter what the frequency)	Frequency of the light
The maximum kinetic energy of the ejected electrons depends on . . .	Intensity of the light	Frequency of the light
At low intensities, ejecting electrons . . .	Takes time	Occurs instantaneously above threshold frequency (never occurs below certain frequency)

Analysis of Results: conflicts with the classical theory about light

Quantum Theory says . . . light (and all electromagnetic radiation) sometimes acts like a particle whose energy depends on its frequency

- light can exhibit properties of both waves and of particles.

Planck's Constant



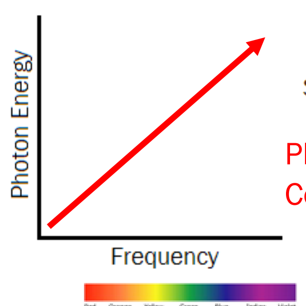
- In 1900, Max Planck was working on the problem of how the radiation an object emits is related to its temperature. He came up with a formula that agreed very closely with experimental data, but the formula only made sense if he assumed that the energy of a vibrating molecule was quantized.
- Based on Planck's work, Einstein proposed that light also delivers its energy in chunks, meaning light consists of little bundles, or quanta, called photons.
- Photon ($\gamma = gamma$) – a particle of pure energy that has momentum
  - massless, and travels at the speed of light, no charge

> Planck actually didn't realize how revolutionary his work was at the time; he thought he was just fudging the math to come up with the "right answer," and was convinced that someone else would come up with a better explanation for his formula.

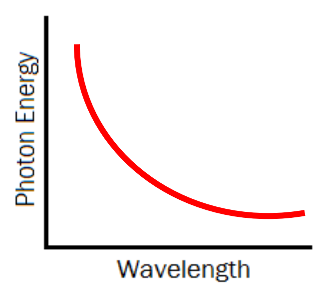
Planck discovered that energy of a photon depends on

$$E_{photon} = hf = \frac{hc}{\lambda}$$

$h = 6.63 \times 10^{-34}$ J•s



Slope = Planck's Constant



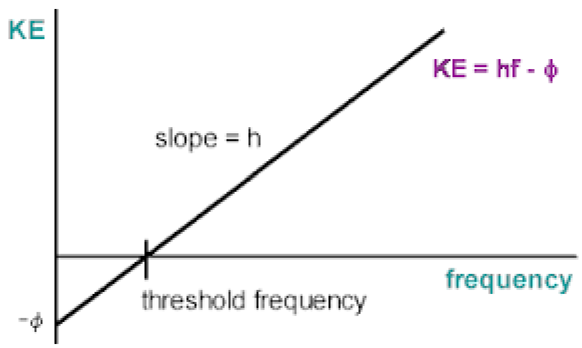
Straighten Graph

Photoelectric Effect Equation

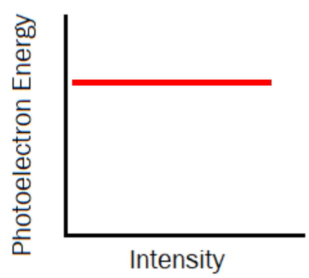
- Work function (Φ)– the amount of energy an electron must absorb to be liberated during the photoelectric effect
- Any excess energy becomes the kinetic energy of the photoelectron when it leaves the metal

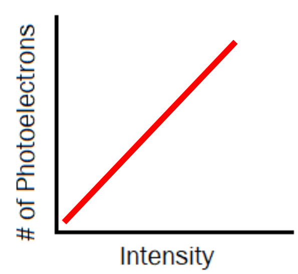
$$KE = hf - \phi$$

* Not on Reference Table



- As the intensity of light increases, the photoelectron energy REMAINS THE SAME but the number of photoelectrons emitted INCREASES





Practice Questions

1. Which color of light has the most energy?

VIOLET

2. Which type of electromagnetic radiation has the most energy?

GAMMMA

3. Determine the energy of a photon that has a frequency of 4.4×10^{14} Hz.

$$E = hf = (6.63 \times 10^{-34}\, J \cdot s)(4.4 \times 10^{14}\, Hz) = 2.9 \times 10^{-19}\ J$$

4. The beam of light from the previous question is set to shine upon a metal with a work function of 1.8×10^{-19} joules. Calculate the energy of the electrons liberated by the beam of light.

$$KE = hf - \phi$$
$$KE = 2.9 \times 10^{-19} J - 1.8 \times 10^{-19} J$$
$$KE = 1.1 \times 10^{-19} J$$

5. The energy of a photon is 2.11 eV.
   a. Determine the energy of the photon in joules.

$$2.11 eV \left(\frac{1.60 \times 10^{-19} J}{1 eV} \right) = 3.38 \times 10^{-19} J$$

   b. Determine the wavelength of the photon.

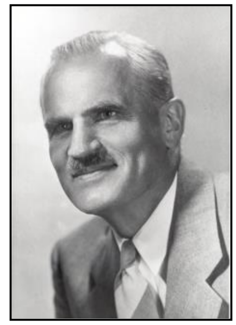
$$\lambda = \frac{hc}{E} = \frac{(6.63 \times 10^{-34}\, J \cdot s)(3.00 \times 10^{8}\, \frac{m}{s})}{3.38 \times 10^{-19} J} = 5.88 \times 10^{-7} m$$

   c. Determine the type of the electromagnetic wave associated with the photon.

When it is visible light must state correct color

$$f = \frac{E}{h} = \frac{3.38 \times 10^{-19} J}{6.63 \times 10^{-34} J \cdot s} = 5.10 \times 10^{14} Hz \quad \text{OR} \quad f = \frac{v}{\lambda} = \frac{3.00 \times 10^{8}\, \frac{m}{s}}{5.88 \times 10^{-7} m} = 5.10 \times 10^{14} Hz$$

Yellow Light



Photon – Particle Collisions

The photoelectric effect demonstrates that a photon, even though it has no mass, has kinetic energy just as a particle does. In 1916, Einstein predicted that the photon should have another particle property, momentum.

In 1922, the American physicist Arthur Compton, tested Einstein's theory by directing X-rays of known wavelength at a graphite target. In 1927, Arthur H. Compton was awarded the Nobel Prize in Physics for his discovery of the particle properties of x-rays.

In the picture below an X-ray photon is striking an electron from a graphite surface. Use the information provided in the pictures to answer the questions below.

Before Collision		After Collision	
p = 10 kg•m/s	p = 0 kg•m/s	p = 5 kg•m/s	p = 5 kg•m/s
(photon)	e	e →	(photon)

DEMO – cathode ray tube creates electron wind which pushes pin wheel

What changes do you observe in the photon after the collision?

The wavelength increases, and the frequency decreases (therefore, it also loses E and p).

In any collision between a photon and a particle, these quantities are conserved:

Momentum and energy are conserved (given to electron).

Photon-electron collision experiments give evidence of which nature of light?

Particle

Which color of light has photons with the greatest momentum?

Since $p = \frac{h}{\lambda}$, the photon with the smallest wavelength has the greatest momentum. Violet.

Matter Waves

French physicist Louis de Broglie proved that a photon's momentum can be represented by the following equation.

$$p = \frac{h}{\lambda}$$

* Not on Reference Table

Note: Actually calculating de Broglie wavelength is HONORS Level.

In 1923 de Broglie suggested that if a wave behaves like a particle. . .

then a particle could behave like a wave.

What wave phenomenon could test this theory?

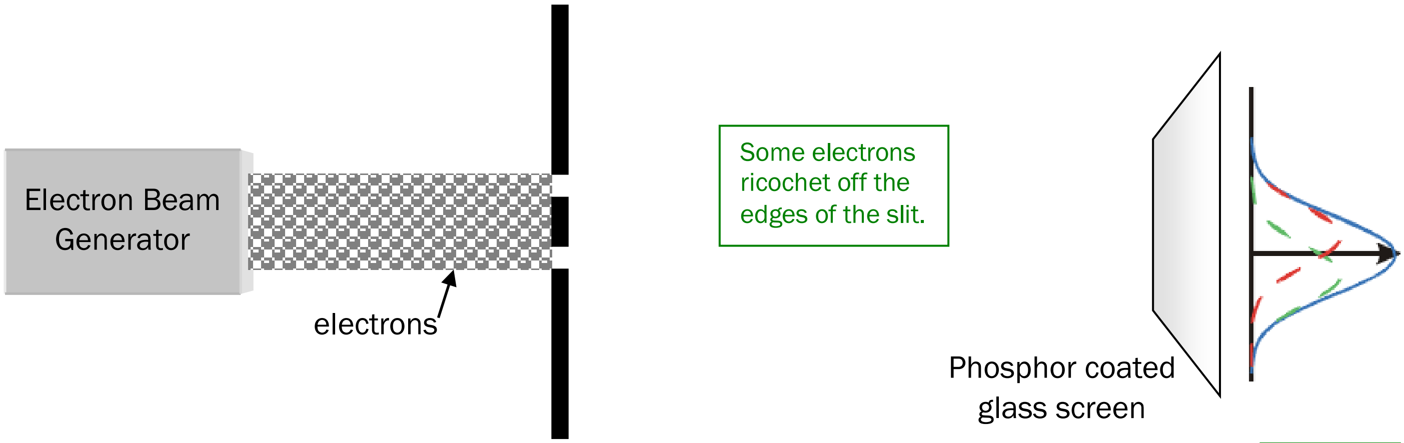
Diffraction and interference

His proposal was so extraordinary that it was ignored by other scientists until Einstein read de Broglie's papers and supported his ideas.

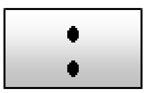
Using the above equation, the ***de Broglie wavelength*** *of the particle could be found.*

http://www.colorado.edu/physics/2000/quantumzone/debroglie.htm

A beam of electrons is directed towards a barrier that has two slits in it. The electrons then travel to a screen placed 2.0 m away.

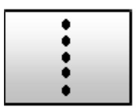


If electrons acted just as particles, what would you expect to see on the screen?



You would only see two bright dots, because only electrons at the opening could pass.

What pattern was seen on the screen? What did this indicate about electrons?



A typical interference pattern was seen. It shows that the electrons behaved similar to waves.

The dual nature of matter:

Matter in motion exhibits particle as well as wave characteristics.

(The wavelengths of ordinary objects, like a thrown baseball, are too small to be detected.)

As the speed of an electron increases, its wavelength decreases.

1. A baseball of mass 0.14kg thrown with a speed of 40 m/s has a $\lambda = 1.2 \times 10^{-34}$ m. Too small for even modern technology.
2. An electron moving at 40 m/s has a $\lambda = 1.8 \times 10^{-5}$ m. Observable

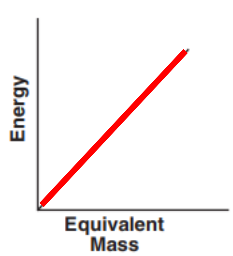
Mass – Energy Relationship

According to Albert Einstein:

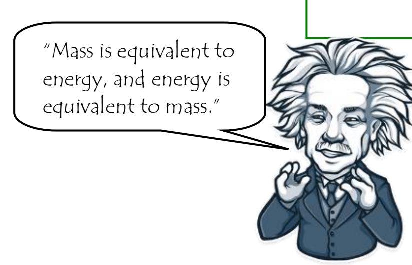
If light (energy) can act as matter, and matter can act as energy....than maybe the two are interchangeable.

- Mass and energy are interconvertible.
- The fundamental source of all energy in the universe is the . . . conversion of mass into energy.

$E = mc^2$



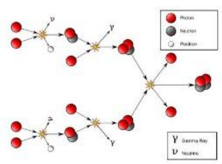
Slope: c^2



1. What are some examples of mass converting into energy and energy into mass?

Fusion – combining atoms

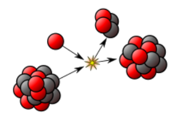
- Sun
- Hydrogen Bomb



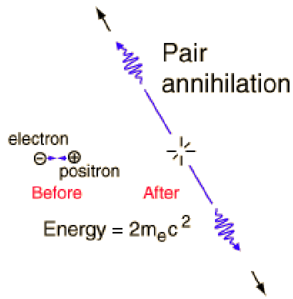
PET Scans – $^{11}C \rightarrow {}^{11}B + e^{+}$ + neutrino then e^{+} and $e^{-} \rightarrow \gamma$

Fission – splitting atoms

- Atomic Bombs
- Nuclear reactor

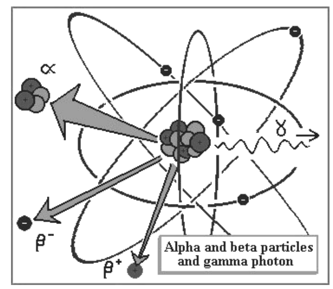


Pair Annihilation – particle and anti-particle turn into pure energy.

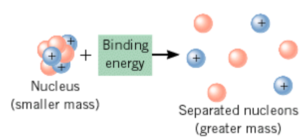


The only known natural nuclear reactor formed 2 billion years ago in Oklo, Gabon. Africa.

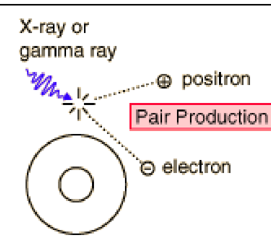
Radioactive Decay – alpha, beta gamma



binding energy – formation of atoms



x-ray or gamma ray turn into electron and positron.



1. Determine the energy equivalent of the rest mass of a proton.

$$E=mc^2 = (1.67\times 10^{-27}\ kg)(3.00 \times 10^8 m/s)^2 = 1.50 \times 10^{-10}\ J$$

2. In a quantum process known as "pair production," an electron and a positron are spontaneously created from energy.
   a. How much energy is needed?

Need to double mass because two of them

$$E=mc^2 = (1.82\times 10^{-30}\ kg)(3.00 \times 10^8 m/s)^2 = 1.64 \times 10^{-13}\ J$$

   b. Often the two particles collide again and destroy each other in a process known as "pair annihilation." How much energy is created?

$$1.64 \times 10^{-13}\ J$$

   c. What quantities are conserved in these two processes?

Energy and matter and charge

This is how neon lights work.

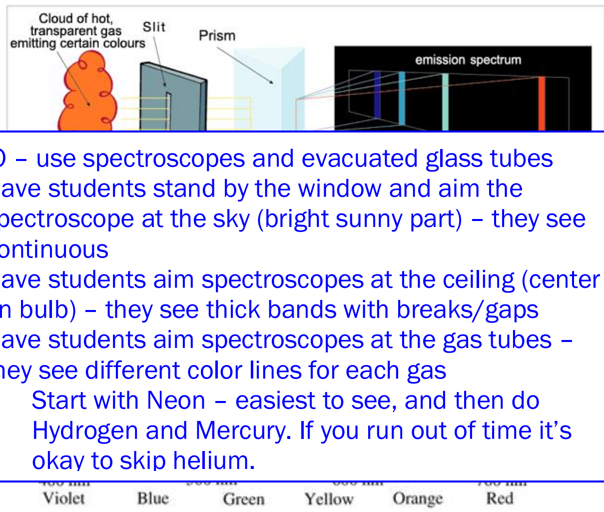
PLASMA TV

We are only observing the spectral lines of radiation emitted in the visible spectrum. Other equipment may reveal radiation in the infrared and ultraviolet ranges or farther.

Atomic Emission and Absorption Spectra

Production of Emission Spectra

1. Low pressure gas is energized by applying a voltage, causing it to heat up.
2. The hot gas emits light energy only at certain well-defined frequencies, as seen through a diffraction grating or prism.

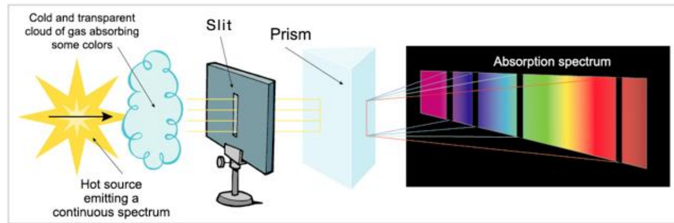


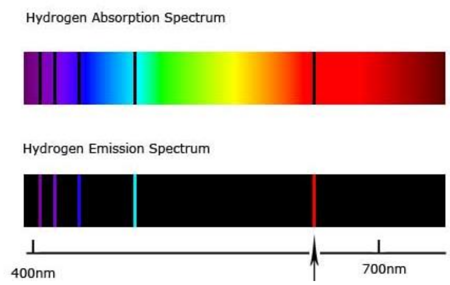
DEMO – use spectroscopes and evacuated glass tubes
- Have students stand by the window and aim the spectroscope at the sky (bright sunny part) – they see continuous
- Have students aim spectroscopes at the ceiling (center on bulb) – they see thick bands with breaks/gaps
- Have students aim spectroscopes at the gas tubes – they see different color lines for each gas
  - Start with Neon – easiest to see, and then do Hydrogen and Mercury. If you run out of time it's okay to skip helium.

The **spectral lines** produced (emission or absorption) are characteristic of the particular element producing them.

Production of Absorption Spectra

1. Light is shone through a cool low pressure gas.
2. A diffraction grating or prism is used to determine what frequencies pass through the gas and which are absorbed.

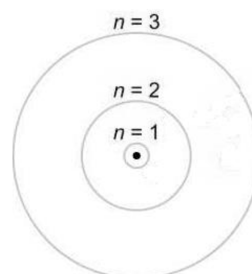




Note that emission and absorption spectral lines occur at the same locations for the same element.

Postulates of the Bohr

Energy levels are quantized; meaning electrons can only move to specific orbits, no where in between.

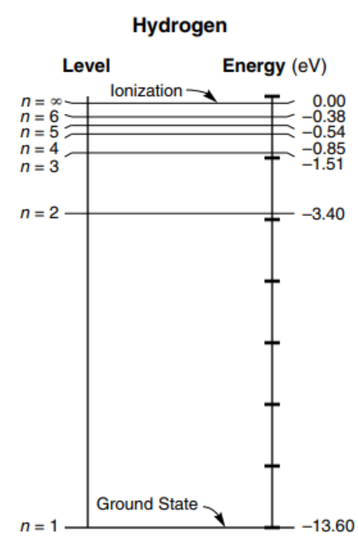


I. Electrons in an atom can only exist in certain well-defined (discrete) stationary states called energy levels or energy states.

- What does each energy level represent? an allowed stable orbit for the electron
- Ground state– closest to nucleus – lowest energy
  - n = 1 E_1 = -13.6 eV

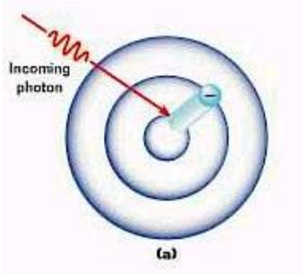
At ordinary temperatures, most electrons are in the ground state, with the electrons relatively close to the nucleus.

- Excited state level – farther from nucleus – more energy
  - n = 2 E_2 = -3.40 eV
  - n = 3 E_3 = -1.51 eV
- Ionization state – electron removed from atom – most energy
  - n = ∞ E = 0 eV



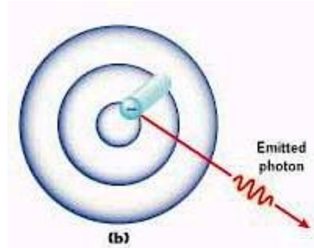
Energy Levels for the Hydrogen Atom

II. Electrons may move from one stationary state to another by emitting or absorbing a quantum of radiation (photon) whose energy equals the difference in the two states.



When a photon (energy) is absorbed. . .

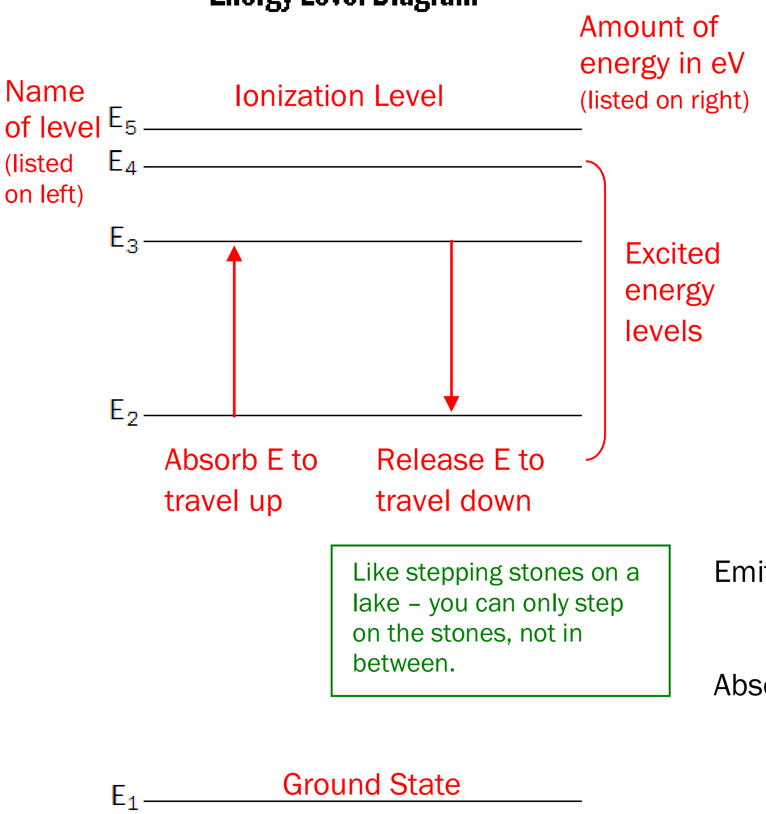
the electron jumps up to a higher energy level



When a photon (energy) is emitted. . .

the electron drops down to a lower energy level

Energy Level Diagram



$$E_{photon} = E_i - E_f$$

E_i = initial energy of electron

E_f = final energy of electron

Emitted photons have positive energy values.

Absorbed photons have negative energy values.

Students need to memorize this!

1. An electron in the n = 4 state relaxes to the n = 2 state of hydrogen and emits a photon. How much energy does the photon have?

   $E_{photon} = E_i - E_f = (-0.85\text{eV}) - (-3.40\text{eV}) = 2.55\text{ eV}$

   E_{photon} positive - emitted

2. A photon whose energy is 1.13 eV is <u>emitted</u> from a hydrogen atom. Determine the energy level transition that this represents.

   n = 6 to n = 3

   This is just guess and check to find levels separated by 1.13 eV. Know that is 6 to 3 because energy is emitted. 3 to 6 would be if absorbed

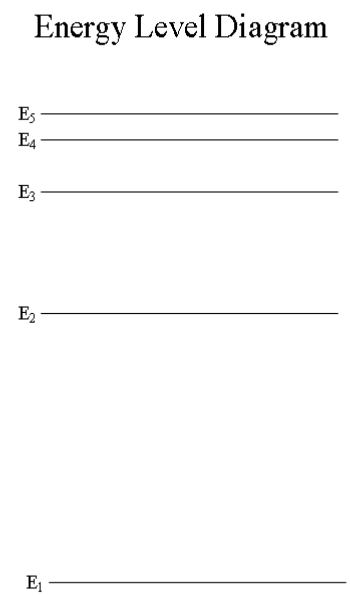
3. How much energy is needed to ionize an atom in the ground state of hydrogen?

$$E_{photon} = E_i - E_f = -13.60eV - 0.00eV = -13.60eV$$

4. A hydrogen atom in the ground state absorbs 15.00 electronvolts of energy and is ionized by losing an electron. How much kinetic energy does this electron have after the ionization?

$$KE_{electron} = E_p - E_{ionization} = 15.00eV - 13.60eV = 1.40eV$$

5. An electron is excited from the ground state to the n = 4 excited state.



a) How many possible different photons may be emitted as the electron relaxes back down to the ground state? Sketch them on the diagram.

6 transitions

b) Which transition produces a photon with the most energy?

4 to 1

c) Which transition produces a photon with the highest frequency?

4 to 1

d) Which transition produces a photon with the longest wavelength?

4 to 3

6. What will happen if hydrogen gas in the ground state is illuminated with light whose photons have an energy of 10.20 eV?

$E_i - E_{photon} = E_f$

E_{photon} negative - absorbed

(-13.60 eV) – (-10.20 eV) = -3.40 eV

The electron will jump to the second energy level.

7. What will happen if hydrogen gas in the ground state is illuminated with light whose photons have an energy of 11.40 eV?

E_{photon} negative - absorbed

$E_i - E_{photon} = E_f$

(-13.60 eV) – (- 11.40 eV) = -2.20 eV

The electron will remain in its energy level

because there is no 2.20 eV level.

A photon's energy is absorbed by an electron in an atom only if the photon's energy corresponds exactly to an energy-level difference possible for the electron. Excitation energies are different for different elements.

8. How much energy is needed for an electron to transition from the n = 2 to the n = 3 energy level? Is this energy absorbed or emitted? Will this result in a bright line or dark line in the atomic spectra?

$E_{photon} = E_i - E_f$

= (- 3.40eV) – (- 1.51eV) = -1.89 eV

Energy is absorbed.

Dark line on absorption spectra

9. An electron makes the transition from level f to b in a mercury atom.

   a. Was energy gained or released by the atom? How much? Express this energy in joules.

Energy was released by the atom.

$E_{photon} = E_i - E_f$

$= (-2.68\text{eV}) - (-5.74\text{eV}) = 3.06\text{ eV}$ (pos. emitted)

$$3.06eV\left(\frac{1.60\times10^{-19}J}{1eV}\right)=4.90\times10^{-19}J$$

   b. Classify the photon as a color from the visible light spectrum.

$$f=\frac{E}{h}=\frac{4.90\times10^{-19}J}{6.63\times10^{-34}J\cdot s}=7.39\times10^{14}Hz$$

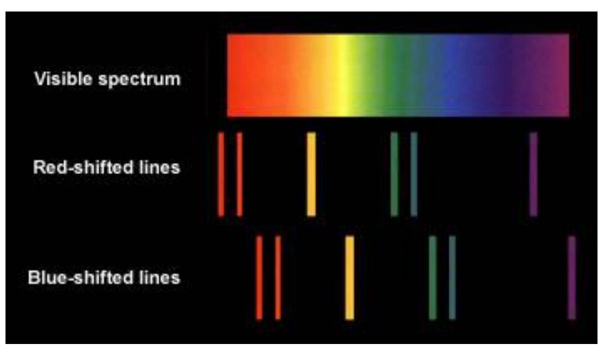
This is the cause of the violet band seen with the spectroscope.

Violet

   c. Determine the wavelength of the photon.

$$\lambda=\frac{c}{f}=\frac{3.00\times10^{8}\,\frac{m}{s}}{7.39\times10^{14}Hz}=4.06\times10^{-7}m$$ OR $$\lambda=\frac{hc}{E}=\frac{(6.63\times10^{-34}J\bullet s)(3.00\times10^{8}\,\frac{m}{s})}{4.90\times10^{-19}J}=4.06\times10^{-7}m$$

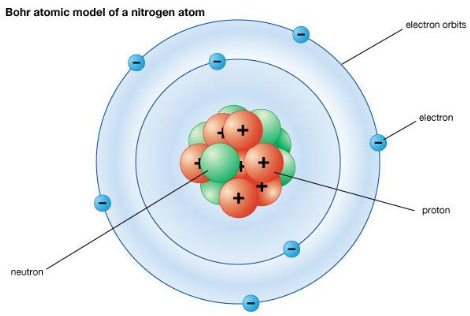
Doppler Shift Revisited



Redshift	Blueshift
The light of an object moving away from an observer is shifted toward a longer wavelength, or toward the color red.	The light of an object moving toward an observer is shifted toward a shorter wavelength, or toward the color blue.

NOTE – the color is not RED or BLUE, it is only shifted toward that end of the light spectrum

Atomic and Nuclear Structure



1. What force holds electrons in orbit around the nucleus?

   Electromagnetic

2. What force holds nucleons together?

   Protons & neutrons

   Strong Force

Name	Property	Type	Range	Strength
Gravitational	Force between objects with mass (energy)	Attractive	Long range	4
Electromagnetic (Electrostatic, Coulomb)	Force between charged objects	Attractive or repulsive	Long range	2
Strong Force	Holds protons and neutrons together in nucleus	Attractive	Short range	1
Weak Force	Involved in radioactive decay	Repulsive	Short range	3

- Universal Mass unit – (u) –1 / 12th the mass of an atom of carbon-12

Particle	Electric Charge (e)	Electric Charge (C)	Mass		Equivalent Energy	
			(kg)	(u)	(J)	(MeV)
Electron	-1	-1.60×10^{-19}	9.11×10^{-31}	0.000549	8.2×10^{-14}	0.511
Proton	+1	$+1.60 \times 10^{-19}$	1.67×10^{-27}	1.0073	1.5×10^{-10} J	938
Neutron	0	0	1.67×10^{-27}	1.0087	1.5×10^{-10} J	939

1 u = 931 MeV

Use $E = mc^2$ convert

Mass Defect and Binding Energy

Mass Defect - the difference between the mass of a nucleus and the sum of the masses of the nucleons that form the nucleus.

Binding Energy equals Mass Defect

Units – universal mass unit (u)

$$m_{defect} = m_{proton} + m_{neutron} - m_{nucleus}$$

*Not on Reference Table

Binding Energy - the energy that is required to combine or separate the nucleons.

Units – Mega-electronvolt (MeV)

1 u = 931 MeV

Binding Energy = Mass Defect

1. An alpha particle (a helium nucleus) consists of two protons and two neutrons and has a mass of 4.0016 u. The mass of a proton is 1.0073 u and the mass of a neutron is 1.0087 u.

   a. Find the mass defect of the helium nucleus.

$$m_{defect} = m_{protons} + m_{neutrons} - m_{nucleum}$$

$$m_{defect} = \left[2(1.0073u) + 2(1.0087u)\right] - 4.0016u$$

$$m_{defect} = .0304\ u$$

   b. Find the binding energy of the helium nucleus in MeV.

$$.0304u\left(\frac{9.31x10^{2}MeV}{1u}\right) = 28.3\ MeV$$

2. A deuterium nucleus has a mass that is 1.53×10^{-3} universal mass units less than the mass of its components. How much energy does this represent?

$$1.53x10^{-3}u\left(\frac{9.31x10^{2}MeV}{1u}\right) = 1.42\ MeV$$

Mass in:	Use equation:	Energy in:
Kilograms (kg)	$E = mc^2$	Joules (J)
Universal mass units (u)	1 u = 931 MeV	MeV

The Standard Model

Probability Function – Schrödinger & Heisenberg

- Standard Model - a theory developed in the 1960's that is used to explain the existence of all the particles that have been observed and the forces that holds atoms together or leads to their decay.
    - According to the Standard Model, the most basic particles are: quarks, leptons, force carriers

The electron is no longer thought to be the smallest particle or charge.

Quarks

1st Generation

Name / Symbol / Charge			
	up, u, $+\frac{2}{3}e$	charm, c, $+\frac{2}{3}e$	top, t, $+\frac{2}{3}e$
	down, d, $-\frac{1}{3}e$ (Most stable)	strange, s, $-\frac{1}{3}e$	bottom, b, $-\frac{1}{3}e$

fractional charge.

Leptons

Name / Symbol / Charge			
	electron, e, −1e	muon, μ, −1e	tau, τ, −1e
	electron neutrino, ν_e, 0	muon neutrino, ν_μ, 0	tau neutrino, ν_τ, 0

2nd and 3rd gen & more massive & decay into 1st gen quickly.

For every particle, there exists . . . an antiparticle

- Antiparticle - a particle having mass, lifetime, and spin identical to associated particle, but having *opposite* charge

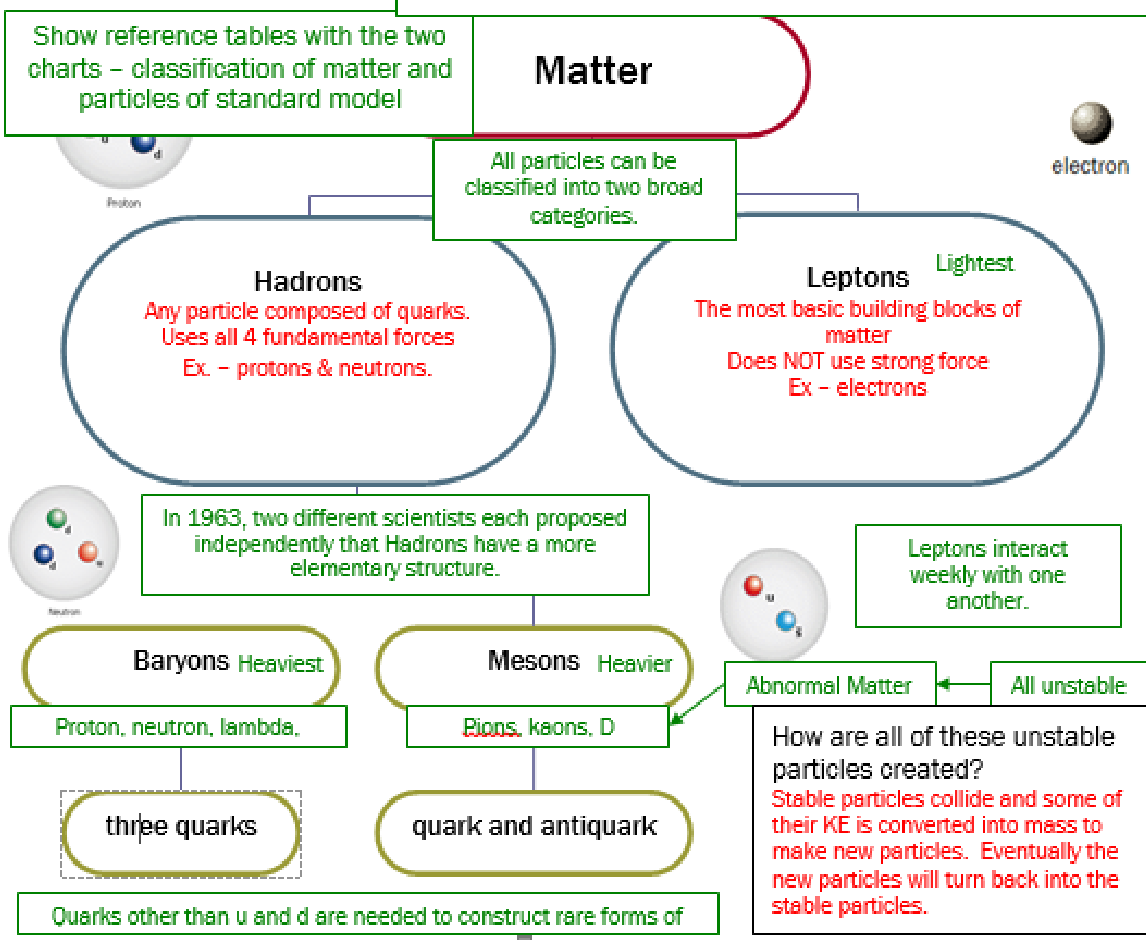
In 1932, scientists though protons and electrons were elementary particles because they were stable. In 1945, experiments at particle accelerators demonstrated that new particles are formed in high energy collisions between 2 known particles. (New particles: unstable, short lived) 300 new particles

Classification of Matter

There are no anti-force carriers to best of our knowledge.

An anti-neutron is made of anti-quarks – lack of charge does not matter

Show reference tables with the two charts – classification of matter and particles of standard model



How are all of these unstable particles created?
Stable particles collide and some of their KE is converted into mass to make new particles. Eventually the new particles will turn back into the stable particles.

Students need to memorize that a proton is uud and a neutron is udd

Particle	Symbol	Composition	Classification	Antiparticle	Antiparticle Symbol	Antiparticle Charge (e)	Antiparticle Composition
Proton	p	uud	Hadron, Baryon	Anitproton	$\bar{p}$	+1e	$\bar{u}\bar{u}\bar{d}$
Neutron	n	udd	Hadron, Baryon	Antineutron	$\bar{n}$	0	$\bar{u}\bar{d}\bar{d}$
Electron	e	e	Lepton	Antielectron (positron)	$\bar{e}$	-1e	$\bar{e}$

1. Determine the charge in Coulombs on the anti-down quark.

The charge on the positron is + 1.60 x 10^{-19} C. On the anti-down quark is + 1/3 e. (5.33x10^{-20}C)

Have students use their reference tables and the Particle of the Standard Model chart while answering these.

2. Determine the electric charge and classification of the following particles:

Particle	Classification	Charge (show work)
Pion ($u\bar{d}$)	Hadron, meson	$(+\frac{2}{3}e)+(+\frac{1}{3}e)=+1e$
Lambda (*uds*)	Hadron, baryon	$(+\frac{2}{3}e)+(-\frac{1}{3}e)+(-\frac{1}{3}e)=0e$
Tau (τ)	Lepton	-1 e
Anti-charm ($\bar{c}$)	Antiquark	-2/3 3 = - 1.07 x 10-19 C
Omega (sss)	Hadron, baryon	$(-\frac{1}{3}e)+(-\frac{1}{3}e)+(-\frac{1}{3}e)=-1e$
Positive kaon ($u\bar{s}$)	Hadron, meson	$(+\frac{2}{3}e)+(+\frac{1}{3}e)=+1e$
Sigma (uus)	Hadron, baryon	$(+\frac{2}{3}e)+(+\frac{2}{3}e)+(-\frac{1}{3}e)=+1e$

3. What are the possible charges a meson can have?

$(-\frac{1}{3}e)+(+\frac{1}{3}e)=0e$ $(-\frac{2}{3}e)+(+\frac{2}{3}e)=0e$ $(-\frac{2}{3}e)+(-\frac{1}{3}e)=-1e$ $(+\frac{2}{3}e)+(+\frac{1}{3}e)=+1e$

Since it is a quark and anti-quark, it will range between -1e and +1e, integers only (no fractions)

4. What are the possible charges a baryon can have?

$(-\frac{1}{3}e)+(-\frac{1}{3}e)+(-\frac{1}{3}e)=-1e$ $(+\frac{2}{3}e)+(+\frac{2}{3}e)+(+\frac{2}{3}e)=+2e$ $(+\frac{2}{3}e)+(-\frac{1}{3}e)+(-\frac{1}{3}e)=0e$

$(+\frac{2}{3}e)+(+\frac{2}{3}e)+(-\frac{1}{3}e)=+1e$

Since it is three, it will range between -1e and +2e, integers only (no fractions)

Bubble Chambers

Bubble Chamber - A device for detecting charged particles and other radiation by means of tracks of bubbles left in a chamber filled with liquid hydrogen or other liquefied gas

- Particles traveling at extremely high speeds collide with each other
- Some of the kinetic energy converts into mass and creates the new particles

It was invented in 1952 by Donald Glaser. The bubble chamber consists essentially of a sealed chamber to be filled with a liquefied gas and constructed so that the pressure inside can be reduced quickly. The liquid is originally at a temperature just below its boiling point. When the pressure is reduced, the boiling point becomes lowered so that it is less than the temperature of the liquid, leaving the liquid superheated. When a charged particle passes through this superheated liquid, it leaves a trail of tiny gas bubbles that can be illuminated and photographed. The track of a charged particle can be used to identify the particle and to analyze complex events in which it may be involved. If a magnetic field is present, the tracks of the particles will be curved, positively charged particles curving in one direction and negatively charged particles curving in the opposite direction. The degree of curvature depends on the mass, speed, and charge of the particle. Neutral particles can be detected indirectly by applying various conservation laws to the events recorded in the bubble chamber or by observing their decay into pairs of oppositely charged particles.

Special Relativity

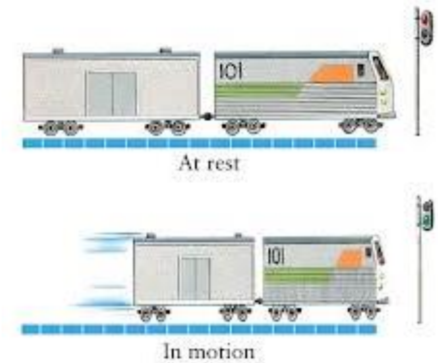
For everyday observations, Newton's laws of motion provide good approximations for describing and predicting motion. If the speed of a particle approaches the speed of light however, a different approach is required to interpret motion. This approach was developed by Albert Einstein in 1905.

Einstein's Special Theory of Relativity is based on two postulates:

1. The laws of physics are the same in all inertial reference frames.
    - Inertial reference frame means the reference frames are moving at constant velocity relative to one another.
2. The speed of light is constant in all reference frames, despite any relative motion between an observer and the light source.

Einstein's theory does not replace Newton's laws. They are a special case when the speeds do not approach the speed of light.

As a result of this theory there are three main consequences:



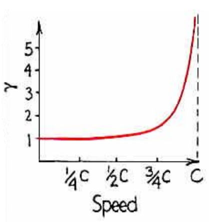
Length Contraction – the length of an object contracts in the direction of motion when measured by a stationary observer.

- The faster the object travels, the shorter it becomes.

Time Dilation – time slows down at high speeds

- Moving clocks run more slowly than stationary clock. The faster the clock moves, the slower the time runs.
- Each observer believes their time is the normal time.

Relativistic Mass – as the velocity of an object approaches the speed of light, the mass increases toward infinity

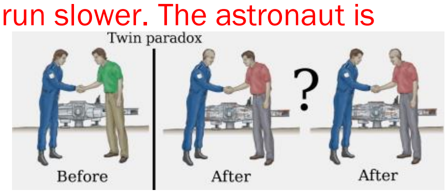


As the mass of an object increases, its kinetic energy increases. It would take an infinite amount of energy to accelerate a massive object to c. Scientist doubt anything will be able to exceed c for this reason.

Can never cross the vertical line which represents speed of light, c

Twin Paradox - The astronaut twin goes on a journey to a distant star in a very fast rocket ship. The scientist twin stays home. When the astronaut twin returns home, who is older?

- According to the scientist, he is at rest while the astronaut was moving, so the astronaut ages more slowly and is younger.
- According the astronaut, he is at rest while the scientist was moving, so the scientist ages more slowly and is younger.
- Resolution:
    - The astronaut's frame of reference is non-inertial (it accelerates), so he really is the one moving at high speeds and his time will run slower. The astronaut is younger.



Name: Answer Key Date: ______________
Honors Physics Test #14 Review

Modern Physics

1. Read Topic 6 – Review Book and Chapters 27 & 28 in text.

2. Terms to know: photoelectric effect, photon, Planck's constant, quantum, photon momentum, photon-electron collisions, matter waves, Bohr Model of the atom, electron cloud, energy level diagram, ground state, orbital, relaxed state, excited state, bright-line spectra, emission spectra, absorption spectra, nuclear force, mass-energy relationship, universal mass unit, Standard Model, hadron, lepton, positron, neutrino, baryon, meson, antiparticle, quark, antimatter, four fundamental forces.

3. What is meant by "the dual nature of light?"
   Light behaves as both a wave and a particle
4. What experiments/phenomena support the wave nature of light?
   Diffraction, Interference, Doppler Effect
5. What experiments/phenomena support the particle nature of light?
   Photoelectric Effect, Photosynthesis, Photocell
6. What are some properties of a photon?
   Has momentum, is massless, travels at speed of light
7. Which color photon has the highest frequency? Wavelength? Energy?
   High f = violet High wavelength = red High E = violet
8. Which type of photon has the highest frequency? Wavelength? Energy?
   High f = gamma High wavelength = Radio/Long Radio High E = gamma
9. How is the momentum of a photon related its wavelength? Frequency?
   Momentum is inversely prop. to wavelength, Momentum is directly prop. to frequency
10. When a photon collides with a particle, what quantities are conserved?
    Momentum and Energy
11. As the speed of an electron increases, what happens to its wavelength?
    Wavelength decreases $p = \frac{h}{\lambda}$ so $m \cdot v = \frac{h}{\lambda}$
12. What is the Bohr Model of the atom? What are its major assumptions?
    Quantized energy levels
13. What are spectral lines and what causes them? What are emission and absorption spectra?
    Lines of visible colors of light emitted when atoms change energy level
    Emission shows the colors emitted by the atom, absorption shows everything else
14. When an electron jumps from the ground state to a higher orbital, what happens?
    Absorbs a photon
15. When an electron jumps from a higher orbital to the ground state, what happens?
    Photon is emitted
16. Be able to read energy level diagrams for hydrogen and mercury and calculate the energy released/absorbed during transitions.
17. Be able to read the Standard Model and Classification of Matter charts.
18. What is the difference between a particle and its antiparticle?
    An antiparticle has the same mass, lifetime and spin, but OPPOSITE chage
19. How many quarks make up a baryon? A meson? A lepton?
    Baryon = 3 quarks Meson = quark + antiquark Lepton = no quarks
20. What are the possibilities for the charge of a baryon?
    + 2 e + 1 e 0 - 1 e

21. Be able to calculate the conversion of mass to energy and vice versa.
    $E = mc^2$
22. Know the relationship between Energy and frequency or wavelength. Be able to graph.
    $E = hf$
23. Explain why a hydrogen atom in the ground state can absorb a 10.2 eV photon, but cannot absorb an 11.0 eV photon.
    It needs to absorb photons with specific energies that match the energy level diagrams.
24. What prevents the nucleus of a helium atom from flying apart?
    Stong Nuclear Force
25. As an electron in an atom moves in a circular path of constant radius around the nucleus, the total energy of the atom (increases, decreases, remains the same)

26. When a source of dim orange light shines on a photosensitive metal, no photoelectrons are ejected from its surface. What could be done to increase the likelihood of producing photoelectrons?
    Change the frequency of the light – orange is not high enough.
27. Infrared electromagnetic radiation incident on a material produces no photoelectrons. When red light of the same intensity is shone on the same material, photoelectrons are emitted from the surface. Using one or more complete sentences, explain why the visible red light causes photoelectric emission, but the infrared radiation does not.
    Visible red light has a higher frequency than infrared light, which means is has more energy
28. A metal surface emits photoelectrons when illuminated by green light. This surface must also emit photoelectrons when illuminated by
    a. Orange light   b. Blue light   c. Yellow light   d. Red light

Directions: Read each question carefully and record your answers in the space provided. Be sure to show all work! Answers should be in significant figures. You will be graded on proper use of the GUESS method.
These will be the same directions on the test. Practice the GUESS method now.

29. How much energy, in joules, would be released if two protons were completely converted into energy? Convert your answer to eV and MeV.

$$E = mc^2 = 2(1.67\times10^{-27}kg)(3.00\times10^{8}\tfrac{m}{s})^2 = 3.01\times10^{-10}J$$

Since it's two protons you need to double the mass.

$$3.01\times10^{-10}J\left(\frac{1eV}{1.60\times10^{-19}J}\right) = 1.88\times10^{9}eV$$

This conversion is on the reference tables.

$$1.88\times10^{9}eV\left(\frac{1MeV}{10^{6}eV}\right) = 1880MeV$$

1 goes with prefix,
10^n goes with base unit

30. A particle has a quark composition of dū. What is its electrical charge in coulombs? What is its classification?

This conversion is on the reference tables.

The classification is Meson

$$-\frac{1}{3}e + -\frac{2}{3}e = -1e\left(\frac{1.60\times10^{-19}C}{1e}\right) = -1.60\times10^{-19}C$$

One quark and one anti-quark
Use the classification of matter chart

ū has opposite charge of u

31. A beam of 5.65×10^{14} Hertz light strikes a metal surface, causing electrons to be ejected. The photoelectrons have a kinetic energy of 1.72×10^{-19} joules. Calculate the work function of the metal.

This is HONORS

$$\phi = hf - KE = (6.63\times10^{-34}J\cdot s)(5.65\times10^{14}Hz) - 1.72\times10^{-19}J = 2.03\times10^{-19}J$$

$KE = E_{photon} - \phi$

32. Calculate the energy of a photon which has a frequency of 3.3×10^{14} Hz.

$$E = hf = (6.63\times10^{-34}J\cdot s)(3.3\times10^{14}Hz) = 2.2\times10^{-19}J$$

Planck's constant, h, is on the reference tables.

33. An electron in a hydrogen atom drops from the n = 3 energy level to the n = 2 energy level.

a. What is the energy, in electronvolts, of the emitted photon?

$$E_{photon} = E_i - E_f = -1.51eV - (-3.40eV) = 1.89eV$$

Look up the hydrogen energy level diagram on the reference tables. Level 3 is initial, level 2 is final.

b. What is the energy, in joules of the emitted photon?

$$1.89eV\left(\frac{1.60\times10^{-19}J}{1eV}\right) = 3.02\times10^{-19}J$$

This conversion is on the reference tables.

c. Calculate the frequency of the emitted radiation.

$$f = \frac{E}{h} = \frac{3.02\times10^{-19}J}{6.63\times10^{-34}J\cdot s} = 4.56\times10^{14}Hz$$

d. Calculate the wavelength of the emitted radiation.

$$\lambda = \frac{v}{f} = \frac{3.00\times10^{8}\,\frac{m}{s}}{4.56\times10^{14}Hz} = 6.58\times10^{-7}m$$

OR

$$\lambda = \frac{hc}{E} = \frac{(6.63\times10^{-34}J\cdot s)(3.00\times10^{8}\,\frac{m}{s})}{3.02\times10^{-19}J} = 6.59\times10^{-7}m$$

34. A carbon nucleus contains six protons and six neutrons and has a mass of 12.0000 u. A proton has a mass of 1.0073 u and a neutron has a mass of 1.0087 u.

a. Calculate is the mass defect of the carbon nucleus.

$$m_{defect} = (m_{proton} + m_{neutron}) - m_{nucleus}$$
$$m_{defect} = [6(1.0073u) + 6(1.0087u)] - 12.0000u$$
$$m_{defect} = 0.0960u$$

This equation needs to be memorized.

b. How much energy does this represent in MeV? In eV?

$$0.0960u\left(\frac{931MeV}{1u}\right) = 89.4MeV = 8.94\times10^{7}eV$$

This conversion is on the reference tables.

c. How much energy does this represent in joules?

$$8.94\times10^{7}eV\left(\frac{1.60\times10^{-19}J}{1eV}\right) = 1.43\times10^{-11}J$$

This conversion is on the reference tables.

35. What is the minimum energy needed to ionize a hydrogen atom in the n = 2 energy state?

(A) 10.2 eV (B) 3.40 eV (C) 1.89 eV (D) 13.6 eV

$$E_{photon} = E_i - E_f = -3.40eV - 0.00eV$$

36. A photon emitted from an excited hydrogen atom has an energy of 3.02 electronvolts. Which electron energy-level transition would produce this photon?

(A) n = 6 to n = 2 (B) n = 2 to n = 6 (C) n = 1 to n = 6 (D) n = 6 to n = 1

$$E_p = E_i - E_f$$
$$= -.38eV - (-3.40eV)$$

37. White light is passed through a cloud of cool hydrogen gas and then examined with a spectroscope. The dark lines observed on a bright background are caused by

(A) constructive interference
(B) the hydrogen emitting all frequencies in white light
(C) the hydrogen absorbing certain frequencies of white light
(D) diffraction of white light

The hydrogen absorbs the colors, so they don't go through, leaving dark bands

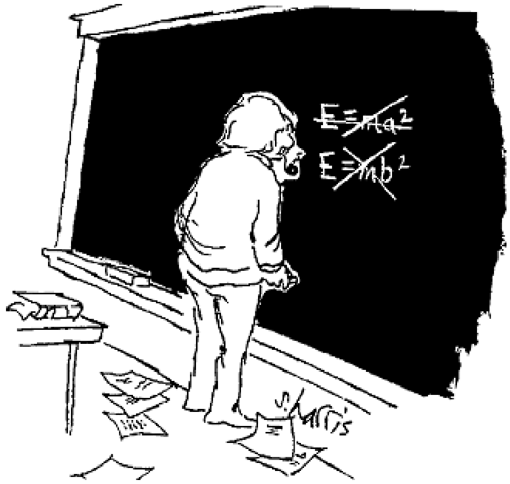
38. The electron in a hydrogen atom drops from energy level n = 2 to energy level n = 1 by emitting a photon having an energy of approximately

(A) 1.6×10^{-18} J (B) 7.4×10^{-18} J (C) 5.4×10^{-19} J (D) 2.2×10^{-18} J

$$E_p = E_i - E_f = -3.40eV - (-13.60eV) = 10.20eV$$
$$10.20eV\left(\frac{1.60\times10^{-19}J}{1eV}\right)$$

39. In the cartoon below, Einstein is contemplating the equation for the principle that

E=mc² calculates how much energy is created when matter converts into energy.



(A) mass always travels at the speed of light in a vacuum
(B) the fundamental source of all energy is the conversion of mass into energy
(C) energy is emitted or absorbed in discrete packets called photons
(D) the energy of a photon is proportional to its frequency.

40. An electron in a hydrogen atom drops from the n = 3 energy to the n = 2 energy level. What is the energy of the emitted photon?

(A) 4.91 eV (B) 3.40 eV (C) 1.89 eV (D) 1.51 eV

$E_{photon} = E_i - E_f = -1.51eV - (-3.40eV)$

41. When yellow light shines on a photosensitive metal, photoelectrons are emitted. As the intensity of the light is decreased, the number of photoelectrons emitted per second

(A) increases (B) decreases (C) remains the same

Lower intensity means fewer photoelectrons because there are fewer photons.

42. After electrons in hydrogen atoms are excited to the n = 3 energy state, how many different frequencies of radiation can be emitted as the electrons return to the ground.

(A) 1 (B) 2 (C) 3 (D) 4

One for level 3 to 1 direction, two for level 3 to 2 then to 1, for a total of 3.

43. The momentum of a photon is inversely proportional to the photon's

(A) weight (B) wavelength (C) mass (D) frequency

$p = \frac{h}{\lambda}$

44. What is the minimum energy required to excite a mercury atom initially in the ground state?

(A) 10.38 eV (B) 4.64 eV (C) 10.20 eV (D) 5.74 eV

At a minimum it goes from level a to b
$E_{photon} = E_i - E_f = -10.38eV - (-5.74eV)$

45. Which combination of quarks would produce a neutral baryon?

(A) uud (B) udd $+\frac{2}{3}e + \frac{2}{3}e - \frac{1}{3}e$ (C) ūūd (D) ūdd

46. A photon of which electromagnetic radiation has the *most* energy?

(A) infrared (B) microwave (C) x-ray (D) ultraviolet

E=hf
Higher frequency means more energy

47. What is the energy of a quantum of light having a frequency of 6.0×10^{14} hertz?

(A) 3.0×10^{8} J (B) 5.0×10^{-7} J (C) 1.6×10^{-19} J (D) 4.0×10^{-19} J

$E = hf = (6.63 \times 10^{-34} J \cdot s)(6.0 \times 10^{-19} Hz)$

48. The energy of a photon varies directly with its

$E = hf$

(A) wavelength (B) speed (C) frequency (D) rest mass

49. Which phenomenon is most easily explained by the particle theory of light?

(A) polarization
(B) diffraction
(C) photoelectric effect
(D) constructive interference

The photons act like particles and knock the electrons out. The other three demonstrate the wave nature of light.

50. Protons and neutrons are composed of smaller particles called

(A) baryons (B) bosons (C) quarks (D) alpha particles

Quarks are the smallest known building blocks of matter

51. As the color of light changes from red to yellow, the frequency of the light

(A) increases (B) decreases (C) remains the same

52. Experiments performed with light indicate that light exhibits

Look at the Electromagnetic Spectrum on the reference tables.

(A) particle properties, only
(B) wave properties, only
(C) both particle and wave properties
(D) neither particle nor wave properties

53. What type of nuclear force holds the protons and neutrons in an atom together?

(A) a strong force that acts over a long range
(B) a weak force that acts over a short range
(C) a strong force that acts over a short range
(D) a weak force that acts over a long range

54. What is the minimum energy required to ionize a hydrogen atom in the n = 3 state?

(A) 5.52 eV (B) 12.09 eV (C) 13.60 eV (D) 1.51 eV

$E_{photon} = E_i - E_f = -1.51eV - 0.00eV$

55. Which electron transition in the hydrogen atom results in the emission of a photon of *greatest* energy?

$E_{photon} = E_i - E_f = -3.40eV - (-13.60eV) = 10.20eV$

(A) n = 4 to n = 2 (B) n = 2 to n = 1 (C) n = 3 to n = 2 (D) n = 5 to n = 3

56. If a deuterium nucleus has a mass of 1.53 x 10^{-3} universal mass units less than its components, this mass represents an energy of

(A) 1.42 MeV (B) 1.38 MeV (C) 1.53 MeV (D) 3.16 MeV

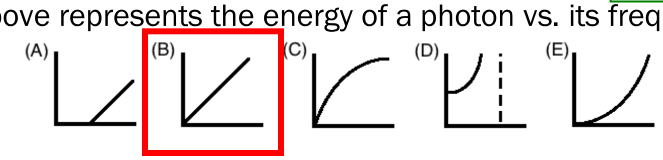
$1.53 \times 10^{-3} u \left(\frac{931 MeV}{1u} \right)$

57. During a collision between a photon and an electron, there is conservation of

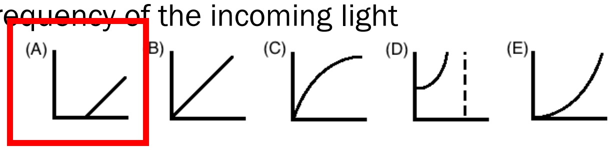
(A) energy, only
(B) both energy and momentum
(C) neither energy nor momentum
(D) momentum, only

Energy and momentum are conserved in a collision. They transfer from one to the other

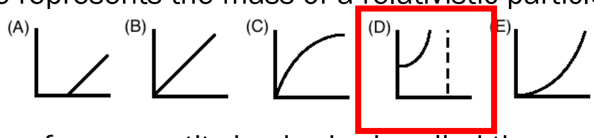
58. Which of the graphs above represents the energy of a photon vs. its frequency?



59. Which of the graphs above represents the maximum kinetic energy of electrons emitted in the photoelectric effect vs. frequency of the incoming light



60. Which of the graphs above represents the mass of a relativistic particle vs. its speed?



61. The smallest discrete value of any quantity in physics is called the

(A) atom (B) molecule (C) proton (D) electron (E) quantum

62. The smallest discrete value of electromagnetic energy is called the

(A) photon (B) proton (C) electron (D) neutron (E) quark

63. Which of the following photons has the highest energy?

(A) x-ray (B) ultraviolet (C) green light (D) microwave (E) radio

64. The photoelectric effect is best explained by the

(A) wave model of light
(B) particle model of light
(C) interference of light waves
(D) diffraction of light waves
(E) Heisenberg uncertainty principle

65. The threshold frequency of zinc for the photoelectric effect is in the ultraviolet range. Which of the following will occur if X-rays are shined on a zinc metal surface?

(A) No electrons will be emitted from the metal
(B) Electrons will be released from the metal but have no kinetic energy.
(C) Electrons will be released from the metal and have kinetic energy
(D) Electrons will be released from the metal but will immediately be recaptured by the zinc atoms
(E) Electrons will simply move from one zinc atom in the metal to another zinc atom in the metal

66. Which of the following is true of the momentum of a photon?

(A) It is proportional to the wavelength of the photon
(B) It is inversely proportional to the wavelength of the photon
(C) It is inversely proportional to the square of the wavelength of the photon
(D) It is proportional to the mass of the photon
(E) It is equal to the energy of the photon

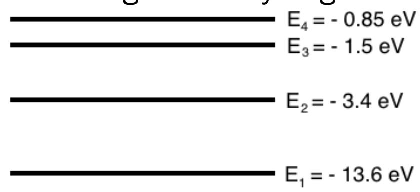
67. Which of the following is true for the de Broglie wavelength of a moving particle

(A) It is never large enough to measure
(B) It is proportional to the speed of the particle
(C) It is inversely proportional to the momentum of the particle
(D) It is equal to Planck's constant
(E) It has no effect on the behavior of electrons

68. An emission spectrum is produced when

(A) electrons in an excited gas jump up to a higher energy level & release photons
(B) electrons in an excited gas jump down to a lower energy level & release photons
(C) electrons are released from the outer orbitals of an excited gas
(D) an unstable nucleus releases energy
(E) light is shined on a metal surface and electrons are released

69. the Consider the electron energy level diagram for hydrogen below



An electron in the ground state of hydrogen atom has an energy of -13.6 eV, and 0 eV is the highest energy level present in a hydrogen atom. Which of the following energies is NOT a possible energy for a photon emitted from hydrogen?

(A) 1.9 eV (B) 13.6 eV (C) 0.65 eV (D) 11.1 eV (E) 10.2 eV

70. The mass of an object increases as its speed increases. This increase comes from

(A) nuclear binding energy
(B) electron energy in the ground state
(C) potential energy being converted to mass by $E = mc^2$
(D) kinetic energy being converted to mass by $E = mc^2$
(E) the lower pressure on the mass

71. The pilot of a spaceship traveling at 90% the speed of light (0.9c) turns on its laser headlights just as it passes a stationary observer. Which of the following statements is true?

(A) The pilot will measure the speed of light coming out of the headlights as c, and the observer will measure the speed of light as 0.9c
(B) The pilot will measure the speed of light coming out of the headlights as c, and the observer will measure the speed of light as 1.9c
(C) The pilot will measure the speed of light coming out of the headlights as 0.9c, and the observer will measure the speed of light as 1.9 c
(D) The pilot will measure the speed of light coming out of the headlights as 1.9c, and the observer will measure the speed of light as 0.9 c
(E) The pilot will measure the speed of light coming out of the headlights as c, and the observer will measure the speed of light as c

72. Two identical precise clocks are started at the same time. One clock is taken on a trip at a very high speed, and the other is left at rest on earth. When the traveling clock returns to earth, it shows that one hour has passed. Which of the following could be the time that has passed on the earth-bound clock?

(A) 30 minutes (B) 45 minutes (C) 59 minutes (D) 1 hour (E) 2 hours

Answers:
29. 3.01×10^{-10} J
1.88×10^{9} eV
1880 MeV
30. – 1.60×10^{-19} C, Meson
31. 2.03×10^{-19} J
32. 2.2×10^{-19} J
33. a. 1.89 eV
b. 3.02×10^{-19} J
c. 4.56×10^{14} Hz
d. 6.58×10^{-7} m
34. a. 0.0960 u
b. 89.4 MeV
8.94×10^{7} eV
c. 1.43×10^{-11} J
35. B
36. A
37. C
38. A
39. B
40. C
41. B
42. C
43. B
44. B
45. B
46. C
47. D
48. C
49. C
50. C
51. A
52. C
53. C
54. D
55. B
56. A
57. B
58. B
59. A
60. D
61. E
62. A
63. A
64. B
65. C
66. B
67. C
68. B
69. D
70. D
71. E
72. E