91525: Demonstrate understanding of Modern Physics

Modern Physics refers to discoveries since approximately 1890 that have caused paradigm shifts in physics theory. Note 3 has a list is for guidance only and is not compulsory. Assessment evidence could be collected by, but is not limited to, the following methods:

- Written report/ Oral presentation/ Investigation/ Multimedia presentation/ Poster Test.

The teacher can determine the time allowance for the assessment, as this is dependent on the situation. Demonstrating understanding of Modern Physics may include descriptions and/or mathematical solutions and/or graphs and/or diagrams. Students should be provided with any mathematical relationships and/or constants required to solve mathematical problems.

Examples of phenomena, concepts, or principles of Modern Physics include:

- The Bohr model of the hydrogen atom: the photon; the quantisation of energy; discrete atomic energy levels; electron transition between energy levels; ionisation; atomic line spectra, the electron volt
- The photoelectric effect
- Wave-particle duality
- Qualitative description of the effects of the strong interaction and Coulombic repulsion, binding energy and mass deficit; conservation of mass-energy for nuclear reactions
- Qualitative treatment of special and general relativity
- Qualitative treatment of quarks and leptons.

Connected Relationships (that might be used – from the previous standard):

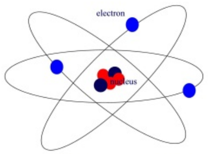
$$E = hf \qquad hf = \phi + E_K \qquad E = \Delta mc^2$$

$$E_n = -\frac{hcR}{n^2} \qquad \frac{1}{\lambda} = R\left(\frac{1}{S^2} - \frac{1}{L^2}\right)$$

The information that follows might be used in the internally assessed standard.

Atomic Spectra

Rutherford's Model is flawed.



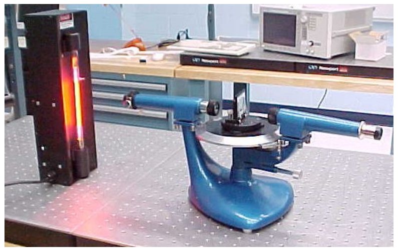
Atomic Planetary Model

If electromagnetic waves are emitted by accelerating charged particles (electrons) being accelerated in orbit about the nucleus

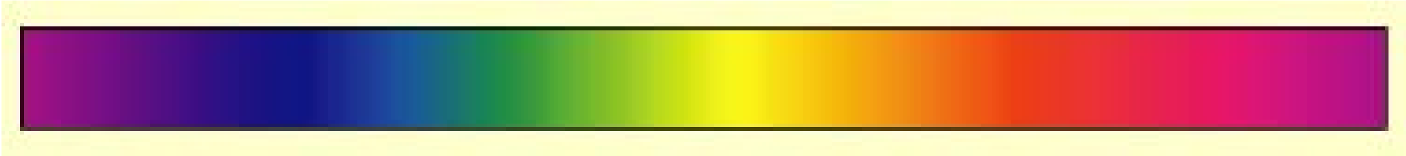
Then…

If electrons are giving off energy, then an electrons potential energy, and the radius of its orbit about the nucleus, should decrease. Any radiating electron would give off all its potential energy in a fraction of a second, and the electron would death spiral into the nucleus.

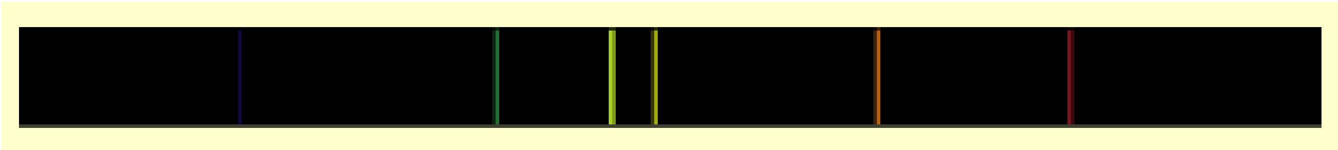
A **spectroscope** breaks up the visible light emitted from a light source into a spectrum, so that we can see exactly which frequencies of light are being emitted.



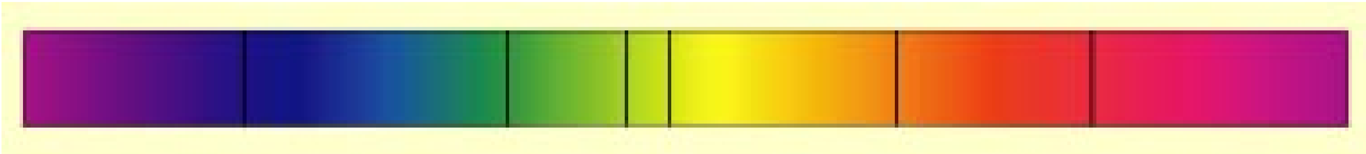
Emission Spectra of liquids and solids: Liquids and **Solids** produce **continuous** spectra because electrons are shared between many atoms, giving a huge range of possible frequencies. The hotter a solid or liquid an object is, the higher the limit of the continuous spectra it emits. E.g. "cool" objects emit the spectra up to red light (that is radio waves, microwaves, infra-red and red light). A "hotter" object emits all of these and orange, yellow, green, blue, indigo and violet so appears white hot. An "even hotter" object emits all of these and ultraviolet, x rays and gamma rays (The ultraviolet catastrophe means that these frequencies are not emitted in equal amounts).



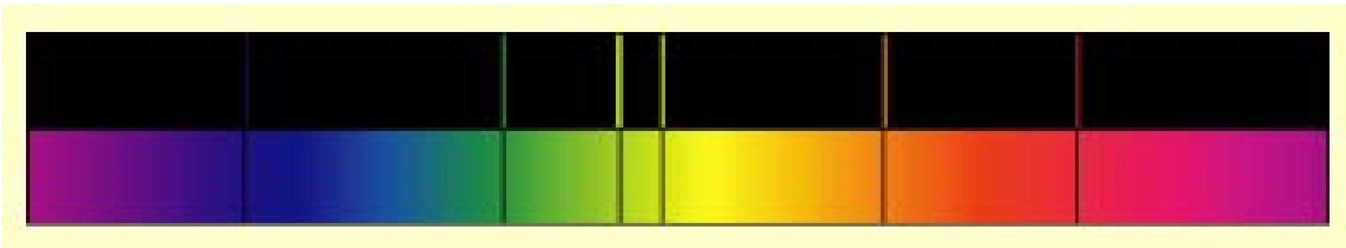
Emission Spectra of gases: Excited **gases** emit **line** spectra due to the excitation of individual electrons (which don't interact with each other).



Absorption Spectra of gases: Gases can also absorb specific frequencies when continuous spectrum is shone through them.



When photons of light pass through a gas, the photons with the same energy as the energy gaps in the atoms can be absorbed. This causes absorption spectra. Because the energy levels are the same, the lines in the emission spectra of an element are in the same position as the lines in the absorption spectra of the same element.



The Rydberg Equation

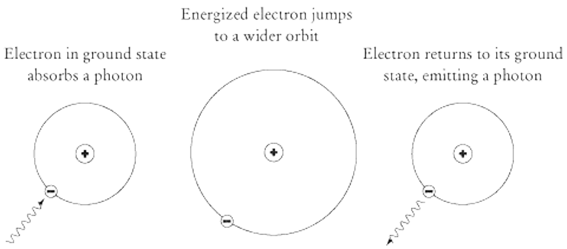
Johannes Robert Rydberg was a Swedish physicist who devised a formula, in 1888, which can be used to predict the wavelengths of photons emitted by changes in the energy level of an electron in a hydrogen atom.

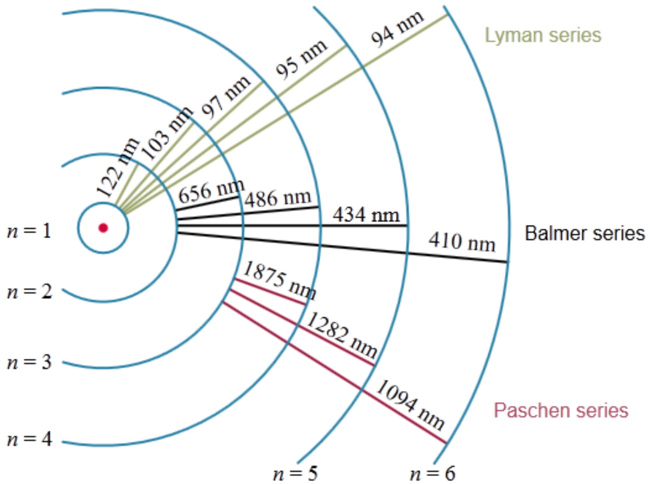
$$\frac{1}{\lambda} = R\left(\frac{1}{S^2} - \frac{1}{L^2}\right)$$

He devised a series using other scientists to help him:

Series Name	Part of spectrum	S
Lyman	Ultraviolet	1
Balmer	Visible	2
Paschen	Infrared	3

(There are other series not mentioned here)





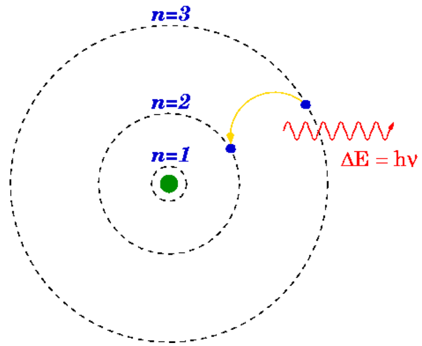
The Bohr Model of the Atom

Niels Bohr sought to refine both Rutherford and Rydberg theories by suggesting that energy travels only in distinct quanta.

He developed an atomic theory that accounts for why electrons do not collapse into nuclei and why there are only particular frequencies for visible light.

Bohr's model was based on the hydrogen atom, since, with just one proton and one electron; it makes for the simplest model.

According to Bohr, the electron of a hydrogen atom can only orbit the proton at certain distinct radii. The closest orbital radius is called the electron's **ground state**. When an electron absorbs a certain amount of energy, it will jump to a greater orbital radius. After a while, it will drop spontaneously back down to its ground state, or some other lesser radius, giving off a photon as it does so.



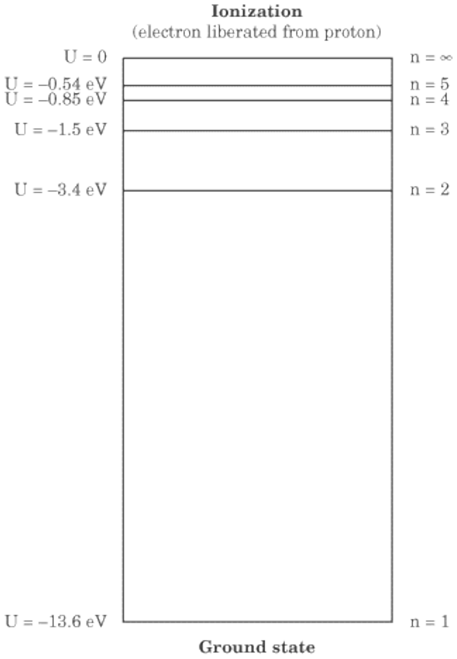
Because the electron can only make certain jumps in its energy level, it can only emit photons of certain frequencies.

Electron Potential Energy

The energy of an electron in a hydrogen atom at its ground state (where n = 1) is –13.6 eV. This is a negative number because we're dealing with *potential* energy: this is the amount of energy it would take to free the electron from its orbit. It is calculated by the equation:

$$E_n = -\frac{hcR}{n^2}$$

When the electron jumps from its ground state to a higher energy level, it jumps by multiples of n.



Electronvolts

Because the amounts of energy involved at the atomic level are so small, it's difficult to talk in terms of joules. Instead, we use the **electron volt** (eV), where 1 eV is the amount of energy involved in accelerating an electron through a potential difference of one volt.

Mathematically, 1 eV = 1.6×10^{-19} J

Frequency and Wavelength of Emitted Photons

An excited hydrogen atom emits photons when the electron jumps to a lower energy state. For instance, a photon at n = 2 returning to the ground state of n = 1 will emit a photon with energy,

E = (-3.4 eV) – (-13.6 eV) = 10.2 eV.

Using Planck's formula, which relates energy and frequency, we can determine the frequency of the emitted photon:

$$f = \frac{E}{h} = \frac{10.2 \text{ eV}}{4.14 \times 10^{-15} \text{ eV} \cdot \text{s}} = 2.46 \times 10^{-15} \text{ Hz}$$

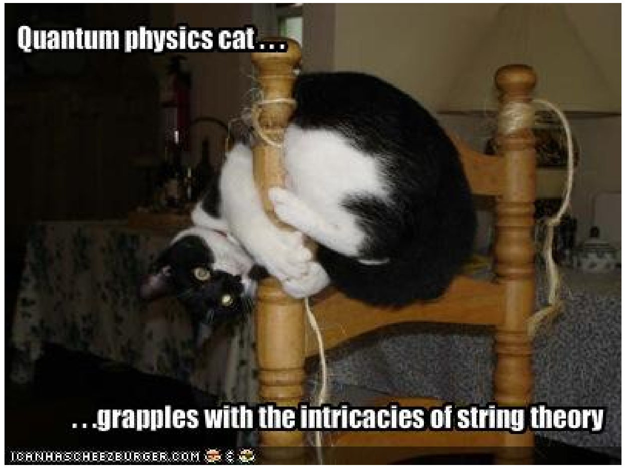
Knowing the frequency means we can also determine the wavelength:

$$\lambda = \frac{c}{f} = 1.22 \times 10^{-7} \text{m}$$

This photon is of slightly higher frequency than the spectrum of visible light: we won't see it as it is ultraviolet radiation. Whenever an electron in a hydrogen atom returns from an excited energy state to its ground state it lets off an ultraviolet photon.

Quantum Physics

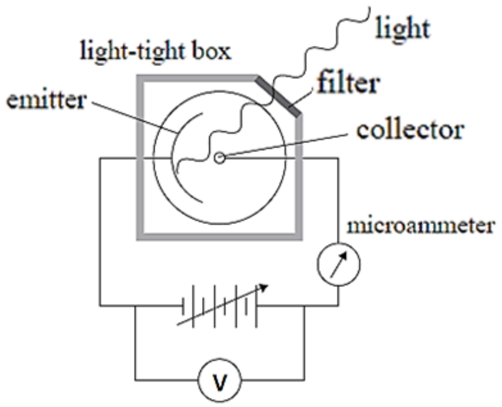
It became clear to Physicists that things at the atomic level are totally unlike anything we find on the level of everyday objects. Physicists had to develop a whole new set of mechanical equations, called "quantum mechanics," to explain the movement of elementary particles. The physics of this "quantum" world demands that we upset many basic assumptions—that light travels in waves, that observation has no effect on experiments, etc.—but the results, from digital cameras to microprocessors, are undeniable. Quantum physics is strange, but it works.



<u>The Photoelectric Effect</u>

Electromagnetic radiation transmits energy, so when visible light, ultraviolet light, X rays, or any other form of electromagnetic radiation shines on a piece of metal, the surface of that metal absorbs some of the radiated energy. Some of the electrons in the atoms at the surface of the metal may absorb enough energy to liberate them from their orbits, and they will fly off. These electrons are called photoelectrons, and this phenomenon, first noticed in 1887 by Hertz, is called the photoelectric effect.

This can be investigated using a photoelectric apparatus:



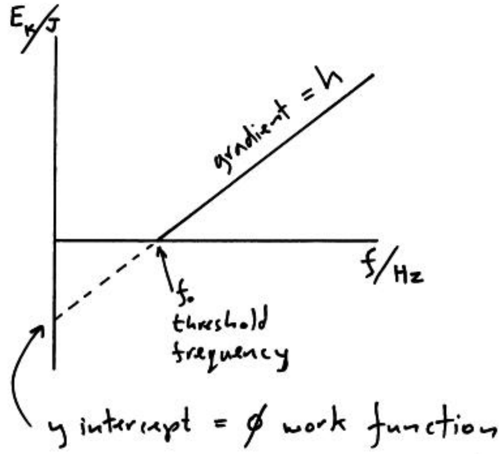
Photoelectric emission is a process during which electrons are ejected from a metal surface by electromagnetic radiation, (e.g. ultraviolet).

- If a clean, **positively charged** zinc plate is exposed to intense white light it will **not** discharge.
- If a clean, **negatively charged** zinc plate is exposed to intense white light it will **not** discharge. No matter how intense the light the plate will **not** discharge, or whether the plate is positively or negatively charged, the plate will **not** discharge.
- If a clean, **positively charged** zinc plate is exposed to an ultraviolet source it will **not** discharge. However, if a clean, **negatively charged** zinc plate is exposed to an ultraviolet source it **will** discharge.
- Only if the plate is negatively charged and the source has a high enough frequency will it discharge. The intensity of the source only affects how long it takes the plate to discharge.
- the plate is not being discharged by ionization (the positive one would also discharge)
- the total amount of energy from the source does not determine whether the plate discharges or not

This leads to the theory that the beams of light and ultraviolet are made up of individual units called **photons**.

The kinetic energy of the electrons can be determined by supplying a stopping potential to attract the released electrons back to the metal so $E_k = eV_s$ (Note this is e x V_s not eV for electron volts).

If a graph of kinetic energy against frequency is drawn



$$hf = \phi + E_k$$

$$hf - \phi = E_k$$

$$E_k = hf - \phi$$

$$y = mx + c$$

Einstein's contribution

Albert Einstein accounted for these discrepancies between the wave theory and observed results by suggesting that electromagnetic radiation exhibits a number of particle properties.

Rather than assuming that light travels as a continuous wave, Einstein drew on Planck's work, suggesting that light travels in small bundles, called **photons**, and that each photon has a certain amount of energy associated with it, called a **quantum**. Planck's formula determines the amount of energy in a given quantum:

$$E = hf$$

Where *h* is a very small number, 6.63 x 10^{-34} Js, called **Planck's constant**, and *f* is the frequency of the beam of light.

Work Function and Threshold Frequency

An electron needs to absorb a certain amount of energy before it can fly off the sheet of metal. That this energy arrives all at once, as a photon, rather than gradually, as a wave, explains why there is no time lapse between the shining of the light and the liberation of electrons.

Every material has a given **work function**,Φ, which tells us how much energy an electron must absorb to be liberated. For a beam of light to liberate electrons, the photons in the beam of light must have a higher energy than the work function of the material. Because the energy of a photon depends on its frequency, low-frequency light will not be able to liberate electrons. A liberated photoelectron flies off the surface of the metal with a kinetic energy given by using the equation:

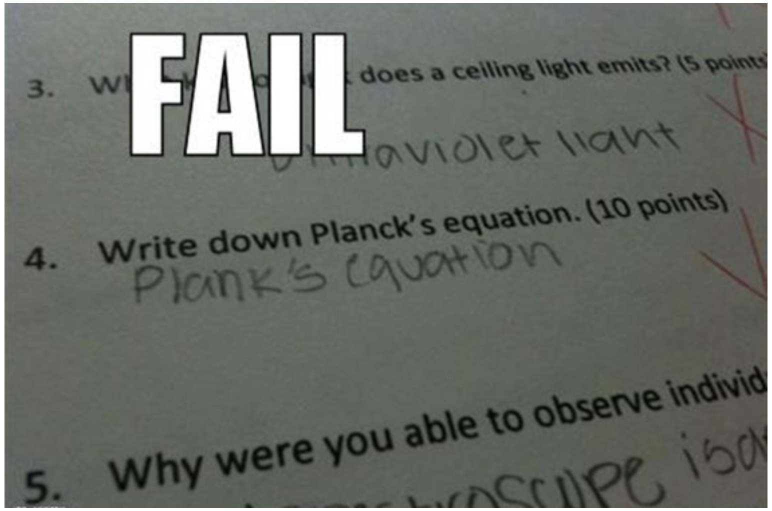
$$hf = \phi + E_K$$ **So also** $$hf = \phi + eV_s$$

(but you are only given the LHS equation)

Wave-Particle Duality

The photoelectric effect shows that electromagnetic waves exhibit particle properties when they are absorbed or emitted as photons.

Young's double-slit experiment, where light forms areas of constructive and destructive interference suggests that electromagnetic radiation travels in waves.



However, the wave theory of electromagnetic radiation makes a number of predictions about the photoelectric effect that prove to be false – look to the right….

	Predictions of the wave theory	Observed result
Intensity	The intensity of the beam of light should determine the kinetic energy of the electrons that fly off the surface of the metal. The greater the intensity of light, the greater the energy of the electrons.	The intensity of the beam of light has no effect on the kinetic energy of the electrons. The greater the intensity, the greater the number of electrons that fly off, but even a very intense low-frequency beam liberates no electrons.
Frequency	The frequency of the beam of light should have no effect on the number or energy of the electrons that are liberated.	Frequency is key: the kinetic energy of the liberated electrons is directly proportional to the frequency of the light beam, and no electrons are liberated if the frequency is below a certain threshold.
Material	The material the light shines upon should not release more or fewer electrons depending on the frequency of the light.	Each material has a certain **threshold frequency**: light with a lower frequency will release no electrons.

Nuclear Physics

Atomic Number, Neutron Number, and Mass Number

An element is defined by the number of protons in the nucleus. For instance, a nucleus with just one proton is hydrogen, a nucleus with two protons is helium, and a nucleus with 92 protons is uranium, the heaviest naturally occurring element. The number of protons in an atomic nucleus determines the **atomic number**, *Z*. In an electrically neutral atom of atomic number *Z*, there will be *Z* protons and *Z* electrons.

The number of neutrons in a nucleus determines the **neutron number**, *N*. Different nuclei of the same atomic number—that is, atoms of the same element—may have different numbers of neutrons. For instance, the nuclei of most carbon atoms have six protons and six neutrons, but some have six protons and eight neutrons. Atoms of the same element but with different numbers of neutrons are called **isotopes**. Electrons weigh very little compared to protons and neutrons, which have almost identical masses. The sum of the atomic number and the neutron number, *Z* + *N*, gives us the **mass number**, *A*.

Einstein's Famous Equation

$$E = \Delta mc^2$$

This equation shows us that mass and energy can be converted into one another.

Chemical reactions result in very small amounts of mass being converted to energy, the fission of large nuclei has a much greater conversion and the fusion of light particles even larger amounts of mass are converted to energy.

Nuclear fission was used in the original atomic bomb, and is the kind of reaction harnessed in nuclear power plants. To produce nuclear fission, neutrons are made to bombard the nuclei of heavy elements—often uranium—and thus to split the heavy nucleus in two, releasing energy in the process. In the fission reactions used in power plants and atomic bombs, two or more neutrons are freed from the disintegrating nucleus. The free neutrons then collide with other atomic nuclei, starting what is called a **chain reaction**.

Reaction	Fuel	Mass converted	Energy created	Equivalent Energy
Chemical	1 kg of coal	4×10^{-10} kg	3.6×10^{7} J	0.00000036 TJ
Fission	1 kg of Uranium 235	1×10^{-4} kg	9×10^{12} J	0.09 TJ
Fusion	1 kg of Hydrogen	6.4×10^{-3} kg	5.76×10^{14} J	576 TJ

Nuclear fusion is ultimately the source of all energy on Earth: fusion reactions within the sun are the source of all the heat that reaches the Earth. These reactions fuse two or more light elements—often hydrogen—together to form a heavier element. As with fission, this fusion releases a tremendous amount of energy. Fusion reactions can only occur under intense heat. Humans have only been able to produce a fusion reaction in the hydrogen bomb, or H-bomb, by first detonating an atomic bomb whose fission produced heat sufficient to trigger the fusion reaction. Scientists hope one day to produce a controllable fusion reaction, since the abundance of hydrogen found in this planet's water supply would make nuclear fusion a very cheap and non-polluting source of energy.

Binding Energy

Atomic nuclei undergo radioactive decay so as to go from a state of high energy to a state of low energy. Atomic nuclei in high-energy states may spontaneously rearrange themselves to arrive at more stable low-energy states.

Mass Defect

The mass of a proton is 1.67338×10^{-27} kg and the mass of a neutron is 1.67483×10^{-27} kg.

The mass of an alpha particle, which consists of two protons and two neutrons, is not
$2\,(1.67338 \times 10^{-27}) + 2\,(1.67483 \times 10^{-27})$
$= 6.69624 \times 10^{-27}$ kg
but is 6.64591×10^{-27} kg.

In general, neutrons and protons that are bound in a nucleus weigh less than the sum of their masses.

We call this difference in mass the **mass defect**, Δm, which in the case of the alpha particle is 0.05051×10^{-27} kg.

A small amount of the matter pulled into the nucleus of an atom is converted into a tremendous amount of energy, the **binding energy**, which holds the nucleus together by throwing the energy away.

The binding energy of the alpha particle is:

$$E = \Delta mc^2$$

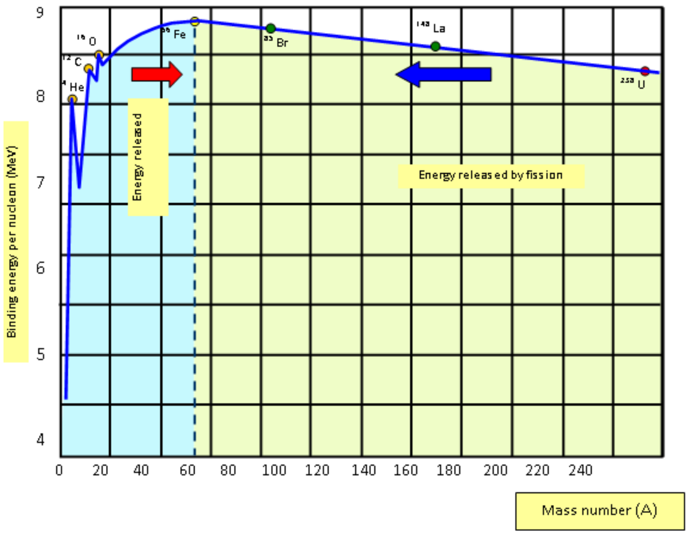
$0.05051 \times 10^{-27} \times (3 \times 10^{8})^2 = 4.5459 \times 10^{-12}$ J

In order to break the hold of the strong nuclear force, an amount of energy equal to or greater than the binding energy must be exerted on the nucleus.

$4.5459 \times 10^{-12} / 4 = 1.136475 \times 10^{-12}$ J

(Sometimes we express binding energy in terms of millions of electronvolts, MeV)

The binding energy per nucleon determines the stability of a nucleus and predicts whether energy will be given out during fission and fusion.



Iron is the most stable nuclei as it has the most binding energy per nucleon of any known element.

If nuclei smaller than iron fuse, they give out energy.

If nuclei bigger than iron undergo fission, they give out energy.

Qualitative treatment of special relativity

Ideas:

- Energy and matter were interchangeable
- the speed of light is the same measured in any inertial frame
- there is a constant relative velocity between any pair of inertial frames

Consequences:

Time dilation: As an observer approaches the speed of light time slows down for them.
Length contraction: The length of an object as measured by an observer relative to whom the object is moving is smaller than the length of that object as measured by an observer from within the same inertial frame as the object.
Mass and energy: As an object speeds up it gains in kinetic energy. Energy has mass, therefore its mass increases. This is only significant at speeds close to the speed of light.

Implications:

1. Everyday speeds are small so the mass of an object can be considered fixed.
2. The mass of a body increases with relative velocity. As the relative velocity increases it becomes increasingly difficult to accelerate it.
3. The mass of an object tends towards infinity at the speed of light. It is impossible for that velocity ever to reach the speed of light.

Qualitative treatment of general relativity

Ideas:

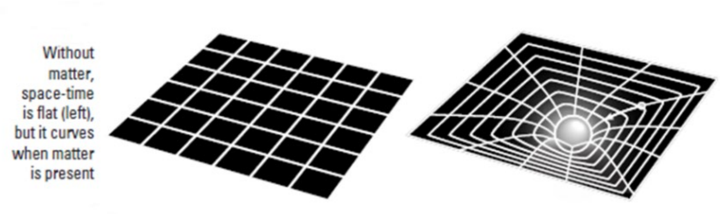
An accelerated system is completely physically equivalent to a system inside a gravitational field (Acceleration and gravity are indistinguishable from each other so they are equivalent to each other). The General theory of relativity is Einstein's theory of gravity.

Consequences:
A clock at the top of a spacecraft will run more quickly than one in the bottom if:

- the spacecraft is accelerating
- the spacecraft is in a gravitational field Accelerations can cause light to bend. Since accelerations are equivalent to gravity then gravity will cause light, and therefore space, to bend.
- Space tells matter where to go. Matter tells space how to bend.

Implications:

1. Black holes
2. Universe might be open, flat or closed



Qualitative treatment of quarks and leptons

– to be added (when time)

Qualitative description of the effects of the strong interaction and Coulombic repulsion

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