RADIOACTIVE ELEMENTS:-

1) PROTACTINIUM (Pa):

Origin of the name: The name is derived from the Greek 'protos', meaning first, as a prefix to the element actinium, which is produced through the radioactive decay of proactinium

Group	Actinides	**Melting point**	1572°C, 2862°F, 1845 K
Period	7	**Boiling point**	4000°C, 7232°F, 4273 K
Block	f	**Density (g cm^{-3})**	15.4
Atomic number	91	**Relative atomic mass**	231.036
State at 20°C	Solid	**Key isotopes**	^{231}Pa
Electron configuration	[Rn] $5f^2 6d^1 7s^2$	**CAS number**	7440-13-3

USES AND PROPERTIES:

Image explanation : The icon is based on the Japanese monogram for 'ichi' – number one. This reflects the origin of the element's name from the Greek 'protos', meaning first.

Appearance : A silvery, radioactive metal.
Uses : Protactinium is little used outside of research.
Biological role : Protactinium has no known biological role. It is toxic due to its radioactivity.
Natural abundance :Small amounts of protactinium are found naturally in uranium ores. It is also found in spent fuel rods from nuclear reactors, from which it is extracted.

2) PLUTONIUM (Pu):

Origin of the name: Plutonium, is named after the then planet Pluto, elements uranium and neptunium. following from the two previous

Group	Actinides	**Melting point**	640°C, 1184°F, 913 K
Period	7	**Boiling point**	3228°C, 5842°F, 3501 K
Block	f	**Density (g cm^{-3})**	19.7
Atomic number	94	**Relative atomic mass**	[244]
State at 20°C	Solid	**Key isotopes**	^{238}Pu, ^{239}Pu, ^{240}Pu
Electron	[Rn] $5f^6 7s^2$	**CAS number**	7440-07-5

USES AND PROPERTIES:

Image explanation :
The image is inspired by Robert Oppenheimer's quote, following the first atomic bomb test in the Nevada desert. 'We knew the world would not be the same. A few people laughed, a few people cried. Most people were silent. I remembered the line from the Hindu scripture, the Bhagavad-Gita. Vishnu is trying to persuade the Prince that he should do his duty and to impress him takes on his multi-armed form and says, "Now I am become Death, the destroyer of worlds." I suppose we all thought that, one way or another.'
Appearance : A radioactive, silvery metal.
Uses : Plutonium was used in several of the first atomic bombs, and is still used in nuclear weapons. The complete detonation of a kilogram of plutonium produces an explosion equivalent to over 10,000 tonnes of chemical explosive.

Plutonium is also a key material in the development of nuclear power. It has been used as a source of energy on space missions, such as the Mars Curiosity Rover and the New Horizons spacecraft on its way to Pluto.
Biological role : Plutonium has no known biological role. It is extremely toxic due to its radioactivity.
Natural abundance : The greatest source of plutonium is the irradiation of uranium in nuclear reactors. This produces the isotope plutonium-239, which has a half-life of 24,400 years.

Plutonium metal is made by reducing plutonium tetrafluoride with calcium.

3) URANIUM (U):

Origin of the name: Uranium was named after the planet Uranus.

Group	Actinides	**Melting point**	1135°C, 2075°F, 1408 K
Period	7	**Boiling point**	4131°C, 7468°F, 4404 K
Block	f	**Density (g cm^{-3})**	19.1
Atomic number	92	**Relative atomic mass**	238.029
State at 20°C	Solid	**Key isotopes**	^{234}U, ^{235}U, ^{238}U
Electron configuration	[Rn] $5f^3 6d^1 7s^2$	**CAS number**	7440-61-1

USES AND PROPERTIES:

Image explanation
The image is based around the common astrological symbol for the planet Uranus.

Appearance :A radioactive, silvery metal.
Uses : Uranium is a very important element because it provides us with nuclear fuel used to generate electricity in nuclear power stations. It is also the major material from which other synthetic transuranium elements are made.

Naturally occurring uranium consists of 99% uranium-238 and 1% uranium-235. Uranium-235 is the only naturally occurring fissionable fuel (a fuel that can sustain a chain reaction). Uranium fuel used in nuclear reactors is enriched with uranium-235. The chain reaction is carefully controlled using neutron-absorbing materials. The heat generated by the fuel is used to create steam to turn turbines and generate electrical power.

In a breeder reactor uranium-238 captures neutrons and undergoes negative beta decay to become plutonium-239. This synthetic, fissionable element can also sustain a chain reaction.
Uranium is also used by the military to power nuclear submarines and in nuclear weapons.
Depleted uranium is uranium that has much less uranium-235 than natural uranium. It is considerably less radioactive than natural uranium. It is a dense metal that can be used as ballast for ships and counterweights for aircraft. It is also used in ammunition and armour.

Biological role : Uranium has no known biological role. It is a toxic metal.
Natural abundance : Uranium occurs naturally in several minerals such as uranite (pitchblende), brannerite and carnotite. It is also found in phosphate rock and monazite sands. World production of uranium is about 41,000 tonnes per year.
Extracted uranium is converted to the purified oxide, known as yellow-cake. Uranium metal can be prepared by reducing uranium halides with Group 1 or Group 2 metals, or by reducing uranium oxides with calcium or aluminium.

4) IODINE 131 (I^{131}):

Origin of the name: The name is derived from the Greek 'iodes' meaning violet.

Group	17	**Melting point**	113.7°C, 236.7°F, 386.9 K
Period	5	**Boiling point**	184.4°C, 363.9°F, 457.6 K
Block	p	**Density (g cm^{-3})**	4.933
Atomic number	53	**Relative atomic mass**	126.904
State at 20°C	Solid	**Key isotopes**	^{127}I
Electron configuration	[Kr] $4d^{10}5s^{2}5p^{5}$	**CAS number**	7553-56-2

USES AND PROPERTIES:

Image explanation: The image is of seaweed. Many species of seaweed contain iodine.
Appearance: A black, shiny, crystalline solid. When heated, iodine sublimes to form a purple vapour.
Uses : Photography was the first commercial use for iodine after Louis Daguerre, in 1839, invented a technique for producing images on a piece of metal. These images were called daguerreotypes.

Today, iodine has many commercial uses. Iodide salts are used in pharmaceuticals and disinfectants, printing inks and dyes, catalysts, animal feed supplements and photographic chemicals. Iodine is also used to make polarising filters for LCD displays.

Iodide is added in small amounts to table salt, in order to avoid iodine deficiency affecting the thyroid gland. The radioactive isotope iodine-131 is sometimes used to treat cancerous thyroid glands.

Biological role

Iodine is an essential element for humans, who need a daily intake of about 0.1 milligrams of iodide. Our bodies contain up to 20 milligrams, mainly in the thyroid gland. This gland helps to regulate growth and body temperature.

Normally we get enough iodine from the food we eat. A deficiency of iodine can cause the thyroid gland to swell up (known as goitre).

Natural abundance

Iodine is found in seawater, as iodide. It is only present in trace amounts (0.05 parts per million); however, it is assimilated by seaweeds. In the past iodine was obtained from seaweed.

Now the main sources of iodine are iodate minerals, natural brine deposits left by the evaporation of ancient seas and brackish (briny) waters from oil and salt wells.

Iodine is obtained commercially by releasing iodine from the iodate obtained from nitrate ores or extracting iodine vapour from the processed brine.

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5) COBALT 60 (Co^{60}):

Origin of the name: The name is derived from the German word 'kobald', meaning goblin.

Group	9	**Melting point**	1495°C, 2723°F, 1768 K
Period	4	**Boiling point**	2927°C, 5301°F, 3200 K
Block	d	**Density (g cm^{-3})**	8.86

Atomic number	27	**Relative atomic mass**	58.933
State at 20°C	Solid	**Key isotopes**	^{59}Co
Electron configuration	[Ar] $3d^7 4s^2$	**CAS number**	7440-48-4

USES AND PROPERTIES:

Image explanation: The image shows a goblin or 'kobold' (often accused of leading German miners astray in their search for tin). In the background is some early Chinese porcelain, which used the element cobalt to give it its blue glaze.

Appearance: A lustrous, silvery-blue metal. It is magnetic.

Uses: Cobalt, like iron, can be magnetised and so is used to make magnets. It is alloyed with aluminium and nickel to make particularly powerful magnets.

Other alloys of cobalt are used in jet turbines and gas turbine generators, where high-temperature strength is important.

Cobalt metal is sometimes used in electroplating because of its attractive appearance, hardness and resistance to corrosion.

Cobalt salts have been used for centuries to produce brilliant blue colours in paint, porcelain, glass, pottery and enamels.

Radioactive cobalt-60 is used to treat cancer and, in some countries, to irradiate food to preserve it.

Biological role

Cobalt is an essential trace element, and forms part of the active site of vitamin B12. The amount we need is very small, and the body contains only about 1 milligram. Cobalt salts can be given to certain animals in small doses to correct mineral deficiencies. In large doses cobalt is carcinogenic.

Cobalt-60 is a radioactive isotope. It is an important source of gamma-rays. It is widely used in cancer treatment, as a tracer and for radiotherapy.

Natural abundance

Cobalt is found in the minerals cobaltite, skutterudite and erythrite. Important ore deposits are found in DR Congo, Canada, Australia, Zambia and Brazil. Most cobalt is formed as a by-product of nickel refining.

A huge reserve of several transition metals (including cobalt) can be found in strange nodules on the floors of the deepest oceans. The nodules are manganese minerals that take millions of years to form, and together they contain many tonnes of cobalt.

6) FANCIUM (Fr):

Origin of the name: Francium is named after France.

Group	1	**Melting point**	21°C, 70°F, 294 K
Period	7	**Boiling point**	650°C, 1202°F, 923 K
Block	s	**Density (g cm^{-3})**	Unknown
Atomic number	87	**Relative atomic mass**	[223]
State at 20°C	Solid	**Key isotopes**	^{223}Fr
Electron configuration	[Rn] $7s^1$	**CAS number**	7440-73-5

USES AND PROPERTIES:

Image explanation: The image reflects the ancient cultural ‘Gallic’ iconography of France, the country that gives the element its name.

Appearance: An intensely radioactive metal.

Uses: Francium has no uses, having a half life of only 22 minutes.

Biological role : Francium has no known biological role. It is toxic due to its radioactivity.

Natural abundance : Francium is obtained by the neutron bombardment of radium in a nuclear reactor. It can also be made by bombarding thorium with protons.

7) ACTINIUM (Ac):

Origin of the name: The name is derived from the Greek 'actinos', meaning a ray.

Group	Actinides	**Melting point**	1050°C, 1922°F, 1323 K
Period	7	**Boiling point**	3200°C, 5792°F, 3473 K
Block	d	**Density (g cm^{-3})**	10
Atomic number	89	**Relative atomic mass**	[227]
State at 20°C	Solid	**Key isotopes**	^{227}Ac
Electron configuration	[Rn] $6d^17s^2$	**CAS number**	7440-34-8

USES AND PROPERTIES:

Image explanation: The Greek symbol ‘alpha’ and metallic ‘rays’ are representative of the element as a source of alpha radiation, and also the origin of its name.

Appearance : Actinium is a soft, silvery-white radioactive metal. It glows blue in the dark because its intense radioactivity excites the air around it.

Uses :Actinium is a very powerful source of alpha rays, but is rarely used outside research.

Biological role : Actinium has no known biological role. It is toxic due to its radioactivity.

Natural abundance: Actinium used for research purposes is made by the neutron bombardment of radium-226. Actinium also occurs naturally in uranium ores.

RADIOACTIVE DEACAY:

Radioactive decay is the spontaneous breakdown of an atomic nucleus resulting in the release of energy and matter from the nucleus. Remember that a radioisotope has an unstable nucleus that does not have enough binding energy to hold the nucleus together. Radioisotopes would like to be stable isotopes so they are constantly changing to try and stabilize. In the process, they will release energy and matter from their nucleus and often transform into a new element. This process, called **transmutation**, is the change of one element into another as a result of changes within the nucleus. The radioactive decay and transmutation process will continue until a new element is formed that has a stable nucleus and is not radioactive. Transmutation can occur naturally or by artificial means.

In radioactive processes, particles or electromagnetic radiation are emitted from the nucleus. The most common forms of radiation emitted have been traditionally classified as alpha (α), beta (β), and gamma (γ) radiation. Nuclear radiation occurs in other forms, including the emission of protons or neutrons or spontaneous fission of a massive nucleus.

Of the nuclei found on Earth, the vast majority are stable. This is so because almost all short-lived radioactive nuclei have decayed during the history of the Earth. There are approximately 270 stable isotopes and 50 naturally occurring radioisotopes (radioactive isotopes). Thousands of other radioisotopes have been made in the laboratory.

Application of Radiology:

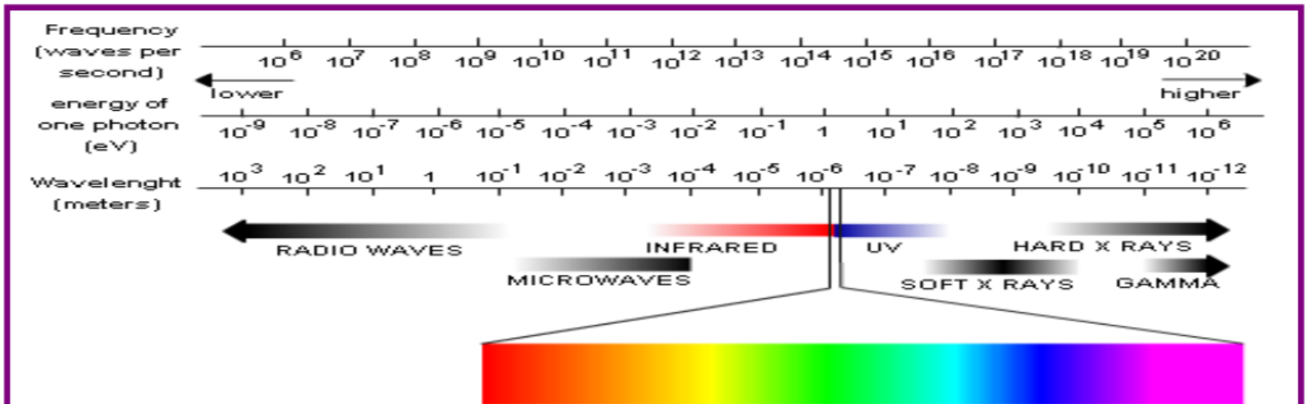
Radiology is concerned with the application of radiation to the human body for diagnostically and therapeutically purposes.
This requires an understanding of:

- **the basic nature of radiation**
- **interaction between radiation and matter**
- **radiation detection**
- **biological effects of radiation**

To evaluate the advantages and disadvantages of the various medical applications of radiation and its limitations

Nature and Origin of Radiation:

There are various kind of radiation which can be classified in electromagnetic radiation (EM) and particle radiation (p). The X-rays and γ-rays are part of the electromagnetic spectrum; both have a wavelength range between 10^{-4} and 10^{1} nm, they differ only in their origin.



The Electromagnetic Spectrum

When interacting with matter EM-radiation shows particle like behavior

The 'particles' are called photons. The energy of the photon and the frequency *u* (or wavelength λ) of the EM-radiation are determined by the Planck constant h:

$$h=6.62^{-34}\ J\cdot s = 4.12\cdot 10^{-21}\ MeV\cdot s$$

$$E = h\cdot\nu = h\cdot\frac{c}{\lambda}$$

The photon energy for X-rays and γ-rays is in the eV to MeV range.

Types of Decay:

α – Particles:

- Heavily charged particles having 2 positive charges that are deflected by electric and magnetic fields
- Harmful to biological cells and can cause total burns when suddenly stopped due to heating effect
- They have short penetrating power

Alpha Decay:

- In this decay, an atomic nucleus emits an α – Particle (2 protons and 2 neutrons) and transforms into an atom with a mass no. than 4 and 2
- Ex: $_{92}U^{238} \longrightarrow {}_{90}Th^{234} + {}_{2}He^{4\ \ 2+}$

  OR
- $_{92}U^{238} \longrightarrow {}_{90}Th^{234} + \alpha$

β – Particles:

- They are high energy electrons and ionize in air
- They have more penetrating power
- β – Particles Causes external radiation hazard to skin and internal hazard occur if the atom the atoms with β – Particles are ingested to body.

Beta Decay:

- A type of radioactive decay in which a beta particles (e^- or positron) is emitted
- In case of e^- emission, it is β^- decay
- In case of positron emission, it is β^+ decay
- Positron is positive decay

β^- decay

- The weak interaction converts a neutron into a proton while emitting an electron and antineutrino
- Neutrinos do not carry electric charge. Because neutrinos are electrically neutral
- But Antineutrino carries the electric charge
- $n^0 \longrightarrow p^+ + e^- + v_e^-$
- Fundamental particles inside neutrons and protons are quarks
- There are two types of quarks i.e, up quarks and down quarks
- Up quarks are those charges are more than +2/3
- And down quarks are those charges are less than -1/3
- Quarks arrange themselves in set of 3 to form protons and neutrons.
- Quarks can charge from up quark to down quark and this changing cause's beta radiation.
- β^- Decay is caused due to conversion of a down quark to an up quark.

Positron Decay or β^+ decay

- Energy is used to convert a proton into an neutron, a positron and a neutrino (v_e)
- energy + $p^+ \longrightarrow n^0 + e^+ + v_e$
- Positron emission occurs when an up quark changes into a down quark
- It does not occur in isolation as it needs energy and it occurs inside the nuclei when absolute value of the binding energy of daughter nuclei is higher than that of mother nucleus.
- Ex: Isotopes of Carbon-11, Po-40, N-13, O-15, etc
  ${}_6C^{11} \longrightarrow {}_5B^{11} + e^+ + v_e$

Electron Capture:

- Electron Capture means when an atomic e^- is captured by a nucleus with the emission of a neutrino.
- energy + $p^+ + e^- \longrightarrow n^0 + v_e$
- This is also called inverse beta decay.
- Ex: ${}_{19}K^{40} + e^- \longrightarrow {}_{18}Ar^{40} + v_e$

- ${}_{19}K^{40}$ undergoes all 3 types of beta decay with a half life of 1.277x 10^9 years
- Some nuclei undergo double beta decay (ββ decay) where charge of nucleus changes by 2 units. But it is very rare.

γ – Particles or Gamma Rays:

- They are electromagnetic radiation of high frequency with short wavelength
- It produced by sub atomic particles interactions.
- They have frequency above 10^{19}Hz and wavelength less than 10 picometers and energy above 100 KeV
- They have high penetrating power and cause damage throughout the body
- Gamma rays can be used to kill living organisms like sterilization
- It is used to treat cancerous cell and CT
- It is used in cyber knife

Cluster Decay:

- A nuclear process in which a radioactive atom emits a cluster of neutrons and protons heavier than an alpha particles.
- It occurs only in a small percentage of decay
- It is limited to heavy radioisotopes that have enough nuclear energy to expel a portion of its nucleus.
    - Ex: $U^{235} \longrightarrow Ne^{24}, Ne^{25}, Mg^{28}, Mg^{29}$
- Tritons and deuterons are occasional radioactive decay products.

Decay Energy:

- The **decay energy** is the energy released by a radioactive decay.
- Radioactive decay is the process in which an unstable atomic nucleus loses energy by emitting ionizing particles and radiation.
- This loss of energy is called decay energy
- This decay, or loss of energy, results in an atom of one type, called the parent nuclide transforming to an atom of a different type, called the daughter nuclide.

Decay calculation

The energy difference of the reactants is often written as Q:

$$Q = (\text{Kinetic energy})_{\text{after}} - (\text{Kinetic energy})_{\text{before}},$$

$$Q = \left((\text{Rest mass})_{\text{before}} \times c^2\right) - \left((\text{Rest mass})_{\text{after}} \times c^2\right).$$

Decay energy is usually quoted in terms of the energy units **MeV** (million electron volts) or **keV** (thousand electron volts).

Types of radioactive decay include

- Gamma Ray
- Beta Decay (decay energy is divided between the emitted electron and the neutrino which is emitted at the same time)
- Alpha Decay

$$W = dm \times \left(\frac{A}{M}\right).$$

or

$$W = E \times \left(\frac{A}{M}\right).$$

- The decay energy is the mass difference ***dm*** between the parent and the daughter atom and particles.
- It is equal to the energy of radiation ***E***.
- If ***A*** is the radioactive activity, i.e. the number of transforming atoms per time, ***M*** the molar mass, then the radiation power ***W*** is:

Example: ^{60}Co decays into ^{60}Ni. The mass difference *dm* is 0.003u. The radiated energy is approximately 2.8 MeV. The molar weight is 59.93. The half life *T* of 5.27 year corresponds to the activity A=(N*(-ln(2)))/T, where N is the number of atoms per mol. Taking care of the units the radiation power for ^{60}Co is 17.9 W/g

Radioactive Isotopes:

Radioactive elements are unstable. They decay, and change into different elements over time. Not all elements are radioactive.

Radioactive Decay and Half Life:

- The time required for one half the atoms of a given amount of a radioactive substance to disintegrate and is also called biological half-life.
- Half life is the period of time it takes for an atom undergoing decay to decrease by half.
- Pharmacologically the time required for the activity of a substance taken into the body to lose one half its initial effectiveness.
- If N_0 is the number of atoms present at any instant t=0, then the time in which $N_0/2$ atoms are disintegrated is called half life.
- The half-life of an element is the time it takes for half of the material you started with to decay.
- Each element has it's own half-life
- Radioactive element decays into a new element. Example C^{14} decays into N^{14}

- The half-life of each element is constant. It's like a clock keeping perfect time.
- We can use half-life to determine the age of a rock, fossil or other artifact.

Exponential decay

An exponential decay can be described by any of the following three equivalent formulas:

$$N(t) = N_0 \left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}}$$
$$N(t) = N_0 e^{-\frac{t}{\tau}}$$
$$N(t) = N_0 e^{-\lambda t}$$

Where:

- N_0 is the initial quantity of the substance that will decay (this quantity may be measured in grams, moles, number of atoms, etc.),
- $N(t)$ is the quantity that still remains and has not yet decayed after a time t,
- $t_{1/2}$ is the half-life of the decaying quantity,
- τ is a positive number called the mean lifetime of the decaying quantity,
- λ is a positive number called the decay constant of the decaying quantity.

The three parameters $t1/2$, τ, and λ are all directly related in the following way:

$$t_{1/2} = \frac{\ln(2)}{\lambda} = \tau \ln(2)$$

where ln (2) is the natural logarithm of 2 (approximately 0.693).

Therefore **$T_{1/2} = 0.693/\lambda$**

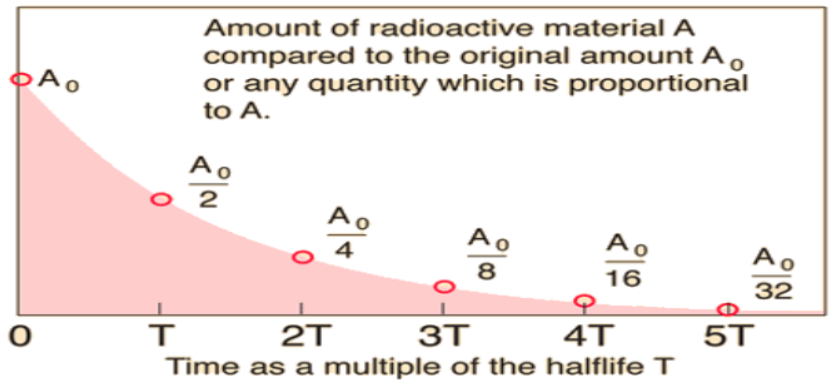
If disintegration constant λ is known then half life can be easily calculated.

$$N(t) = N_0 \left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}} = N_0 2^{-t/t_{1/2}}$$
$$= N_0 e^{-t \ln(2)/t_{1/2}}$$
$$t_{1/2} = \frac{t}{\log_2(N_0/N(t))} = \frac{t}{\log_2(N_0) - \log_2(N(t))}$$
$$= \frac{1}{\log_{2^t}(N_0) - \log_{2^t}(N(t))} = \frac{t \ln(2)}{\ln(N_0) - \ln(N(t))}$$

Regardless of how it's written, we can plug into the formula to get

- $N(0) = N_0$ as expected (this is the definition of "initial quantity")
- $N\left(t_{1/2}\right) = \frac{1}{2}N_0$ as expected (this is the definition of half-life)
- $\lim_{t\to\infty} N(t) = 0$; i.e., amount approaches zero as t approaches infinity as expected (the longer we wait, the less remains).

$$A = A_0 2^{\frac{-t}{T_{1/2}}} = A_0 e^{\frac{-.693\,t}{T_{1/2}}}$$



Heisenberg Uncertainty Principle

- The uncertainty principle states that the position and velocity cannot both be measured, exactly, at the same time (actually pairs of position, energy and time)
- Uncertainty principle derives from the measurement problem, the intimate connection between the wave and particle nature of quantum objects
- The change in a velocity of a particle becomes more ill defined as the wave function is confined to a smaller region
- The wave nature to particles means a particle is a wave packet, the composite of many waves
- Many waves = many momentums, observation makes one momentum out of many
- Exact knowledge of complementarities pairs (position, energy, time) is impossible
- Complementarities also means that different experiments yield different results (e.g. the two slit experiment)
- Therefore, a single reality cannot be applied at the quantum level
- The mathematical form of the uncertainty principle relates complementary to Planck's constant
- Classical physics was on loose footing with problems of wave/particle duality, but was caught completely off-guard with the discovery of the uncertainty principle.
- The uncertainty principle also called the Heisenberg Uncertainty Principle, or Indeterminacy Principle, articulated (1927) by the German physicist Werner Heisenberg, that the position and the velocity of an object cannot both be measured exactly, at the same time, even in theory. The very concepts of exact position and exact velocity together, in fact, have no meaning in nature.

- Ordinary experience provides no clue of this principle. It is easy to measure both the position and the velocity of, say, an automobile, because the uncertainties implied by this principle for ordinary objects are too small to be observed. The complete rule stipulates that the product of the uncertainties in position and velocity is equal to or greater than a tiny physical quantity, or constant (about 10^{-34} joule-second, the value of the quantity h (where h is Planck's constant). Only for the exceedingly small masses of atoms and subatomic particles does the product of the uncertainties become significant.
- Any attempt to measure precisely the velocity of a subatomic particle, such as an electron, will knock it about in an unpredictable way, so that a simultaneous measurement of its position has no validity. This result has nothing to do with inadequacies in the measuring instruments, the technique, or the observer; it arises out of the intimate connection in nature between particles and waves in the realm of subatomic dimensions.
- Every particle has a wave associated with it; each particle actually exhibits wavelike behavior. The particle is most likely to be found in those places where the undulations of the wave are greatest, or most intense. The more intense the undulations of the associated wave become, however, the more ill defined becomes the wavelength, which in turn determines the momentum of the particle. So a strictly localized wave has an indeterminate wavelength; its associated particle, while having a definite position, has no certain velocity. A particle wave having a well-defined wavelength, on the other hand, is spread out; the associated particle, while having a rather precise velocity, may be almost anywhere. A quite accurate measurement of one observable involves a relatively large uncertainty in the measurement of the other.
- The uncertainty principle is alternatively expressed in terms of a particle's momentum and position. The momentum of a particle is equal to the product of its mass times its velocity. Thus, the product of the uncertainties in the momentum and the position of a particle equals h/(2) or more. The principle applies to other related (conjugate) pairs of observables, such as energy and time: the product of the uncertainty in an energy measurement and the uncertainty in the time interval during which the measurement is made also equals h/(2) or more. The same relation holds, for an unstable atom or nucleus, between the uncertainty in the quantity of energy radiated and the uncertainty in the lifetime of the unstable system as it makes a transition to a more stable state.
- The uncertainty principle, developed by W. Heisenberg, is a statement of the effects of wave-particle duality on the properties of subatomic objects. Consider the concept of momentum in the wave-like microscopic world. The momentum of wave is given by its wavelength. A wave packet like a photon or electron is a composite of many waves. Therefore, it must be made of many momentums. But how can an object have many momentums?
- Of course, once a measurement of the particle is made, a single momentum is observed. But, like fuzzy position, momentum before the observation is intrinsically uncertain. This is what is know as the uncertainty principle, that certain quantities, such as position, energy and time, are unknown, except by probabilities. In its purest form, the uncertainty principle states that

accurate knowledge of complementarity pairs is impossible. For example, you can measure the location of an electron, but not its momentum (energy) at the same time.

- A characteristic feature of quantum physics is the principle of complementarity, which "implies the impossibility of any sharp separation between the behavior of atomic objects and the interaction with the measuring instruments which serve to define the conditions under which the phenomena appear." As a result, "evidence obtained under different experimental conditions cannot be comprehended within a single picture, but must be regarded as complementary in the sense that only the totality of the phenomena exhausts the possible information about the objects." This interpretation of the meaning of quantum physics, which implied an altered view of the meaning of physical explanation, gradually came to be accepted by the majority of physicists during the 1930's.
- Mathematically we describe the uncertainty principle as the following, where `x' is position and `p' is momentum:

$$\Delta x \Delta p > \frac{h}{2\pi}$$

- This is perhaps the most famous equation next to $E=mc^2$ in physics. It basically says that the combination of the error in position times the error in momentum must always be greater than Planck's constant. So, you can measure the position of an electron to some accuracy, but then its momentum will be inside a very large range of values. Likewise, you can measure the momentum precisely, but then its position is unknown.
- Notice that this is not the measurement problem in another form, the combination of position, energy (momentum) and time are actually undefined for a quantum particle until a measurement is made (then the wave function collapses).
- Also notice that the uncertainty principle is unimportant to macroscopic objects since Planck's constant, h, is so small (10^{-34}). For example, the uncertainty in position of a thrown baseball is 10^{-30} millimeters.
- The depth of the uncertainty principle is realized when we ask the question; is our knowledge of reality unlimited? The answer is no, because the uncertainty principle states that there is a built-in uncertainty, indeterminacy, unpredictability to Nature.

Units of Radioactivity:

- The number of decays per second, or activity, from a sample of radioactive nuclei is measured in becquerel (Bq), after Henri Becquerel.
- One decay per second equals one becquerel.
- An older unit is the curie, named after Pierre and Marie Curie.
- One curie is approximately the activity of 1 gram of radium and equals (exactly) 3.7×10^{10} becquerel.

- The activity depends only on the number of decays per second, not on the type of decay, the energy of the decay products, or the biological effects of the radiation

Explained: rad, rem, sieverts, becquerels:

Sometimes it must seem as though reports on releases of radioactive materials from Japan's Fukushima Daiichi nuclear powerplant in the wake of the devastating earthquake and tsunami are going out of their way to confuse people. Some reports talk about **millisieverts while others talk about rem or becquerels,** when what most people really want to know is much simpler: Can I drink the milk? Is it safe to go home? Should people in California be worried?

There are a number of reasons for the confusion. In part, it's the usual disparity between standard metric units and the less-standard units favored in the United States, added to the general confusion of reporters dealing with a fast-changing situation (for example, some early reports mixed up microsieverts with millisieverts — a thousandfold difference in dose). Others are more subtle: The difference between the raw physical units describing radiation emitted by a radioactive material (**measured in units like curies and becquerels**), versus measurements designed to reflect the different amounts of radiation energy absorbed by a mass of material (**measured in rad or gray**), and those that measure the relative biological damage in the human body (**using rem and sieverts**), which depends on the type of radiation. (**Rem, rad and gray are all used as the plural as well as the singular form for those units**).

"Just knowing how much energy is absorbed by your body is not enough" to make meaningful estimates of the effects, explains Jacquelyn Yanch, a senior lecturer in MIT's Department of Nuclear Science and Engineering who specializes in the biological effects of radiation. "That's because energy that comes in very close together," such as from alpha particles, is more difficult for the body to deal with than forms that come in relatively far apart, such as from gamma rays or x-rays, she says.

Because x-rays and gamma rays are less damaging to tissue than neutrons or alpha particles, a conversion factor is used to translate the **rad** or gray into other units such as **rem** (from Radiation Equivalent Man) or sieverts, which are used to express the biological impact.

Some things are clear: A radiation dose of 500 millisieverts (mSv) or more can begin to cause some symptoms of radiation poisoning. Studies of those exposed to radiation from the atomic bomb blast at Hiroshima showed that for those who received a whole-body dose of 4,500 mSv, about 50 percent died from acute radiation poisoning. By way of comparison, the average natural background radiation in the United States is 2.6 mSv. The legal limit for annual exposure by nuclear workers is 50 mSv, and in Japan that limit was just raised for emergency workers to 250 mSv.

The highest specific exposures reported so far were of two workers at the Fukushima plant who received doses of 170 to 180 mSv on March 24 — lower than the new Japanese standard, but still enough to cause some symptoms (reports say the men had rashes on the areas exposed to radioactive water).

"Everything we know about radiation suggests that if you get a certain dose all at once, that's much more serious than if you get the same dose over a long time," Yanch says. The rule of thumb is that a dose spread out over a long period of time is about half as damaging as the same dose delivered all at once, but Yanch says that's a conservative estimate, and the real equivalence may be closer to one-tenth that of a rapid dose.

Basic conversions:

1 gray (Gy) = 100 rad
1 rad = 10 milligray (mGy)
1 sievert (Sv) = 1,000 millisieverts (mSv) = 1,000,000 microsieverts (μSv)
1 sievert = 100 rem
1 becquerel (Bq) = 1 count per second (cps)
1 curie = 37,000,000,000 becquerel = 37 Gigabecquerels (GBq)

For x-rays and gamma rays, 1 rad = 1 rem = 10 mSv
For neutrons, 1 rad = 5 to 20 rem (depending on energy level) = 50-200 mSv
For alpha radiation (helium-4 nuclei), 1 rad = 20 rem = 200 mSv

Effects of Radiation