**MODERN PHYSICS**

# GUPTA CLASSES

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# PHOTOELECTRIC EFFECT

**Planck's quantum theory: Wave-particle duality:**

1. Energy of each photon depends only on the frequency ($\nu$) and is given by; $E = h\nu$ where h is Planck's constant.
2. In any interaction, the photon either gives up all of its energy or none of it.
3. According to Einstein's mass-energy equivalence principle $E = mc^2$
4. However rest mass of photon is zero but in motion equivalent mass of photon is given by $m = \frac{h\nu}{c^2}$.
5. Energy of photon is totally kinetic.
6. The momentum p of each photon is given by: $p = mc = \frac{h\nu}{c} = \frac{h}{\lambda}$
7. The above equation involves the particle aspect of photons (momentum) while the right hand side involves the wave aspect (wavelength) and the Planck's constant is the bridge between the two sides. This shows that electromagnetic radiation exhibits a wave-particle duality. In certain circumstances, it behaves like a wave, while in other circumstances it behaves like a particle.

**de Broglie wavelength :** The wave particle is not sole monopoly of electromagnetic waves. Even a material particle in motion (according to de Broglie) will have a wavelength.

1. The de Broglie wavelength $\lambda$, of the matter waves is given by: $\lambda = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$ where E is kinetic energy of particle.
2. If a particle of mass m kg and charge q coulomb is accelerated from rest through a potential difference of V volt. Then $\frac{1}{2}mv^2 = qV$ or $mv = \sqrt{2mqV}$ Hence $\lambda = \frac{h}{\sqrt{2mqV}} = \frac{12.34}{\sqrt{V}}$ Å

**Photoelectric effect:** When light of suitable frequency (electromagnetic radiation) is allowed to fall on a metal surface, electrons are emitted from the surface. These electrons are known photoelectrons and effect is known as photoelectric effect.

**Laws of photoelectric effect:**

1. The kinetic energy of the emitted electron is independent of intensity of incident radiation. But the photoelectric current increases with the increase of intensity of incident radiation.
2. The kinetic energy of the emitted electron depends on the frequency of the incident radiation. It increases with the increase of frequency of incident radiation.
3. If the frequency of the incident radiation is less than a certain critical value, then photoelectric emission is not possible. This frequency is known as threshold frequency. This threshold frequency varies from emitter to emitter, i.e., depends on the material.
4. There is no time lag between the arrival of light and the emission of photoelectrons, i.e.. it is an instantaneous phenomenon.

**Failure of wave theory:** Wave theory of light could not explain the laws of photoelectric effect.

1. According to wave theory, the kinetic energy of the emitted electron should increase with the increase of intensity of incident radiation.
2. Kinetic energy of the emitted electron does not depend on the frequency of incident radiation according to wave theory.
3. Wave theory failed to explain the existence of threshold frequency.
4. According to wave theory there must be a time lag between the arrival of light and emission of photoelectrons.

**Einstein's theory of photoelectric effect:** Einstein explained the laws of photoelectric effect on the basis of Planck's quantum theory of radiation. Einstein treated photoelectric effect as a collision between a photon and an atom in which photon is absorbed by the atom and an electron is emitted.

1. According to law of conservation of energy, $h\nu = h\nu_o + \frac{1}{2}mv^2$, where $h\nu$ is the energy of the incident photon; $h\nu_o$ is the minimum energy required to detach the electron from the atom (work function or ionisation energy) and ½ $mv^2$ is the kinetic energy of the emitted electron.
2. The above equation is known as Einstein's photoelectric equation. Kinetic energy = ½ $mv^2 = h(\nu - \nu_o) = h\nu - W$

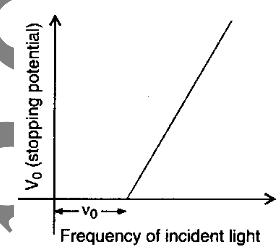
**Explanation of laws of photoelectric effect:**

1. The KE of the emitted electron increases with the increase of frequency of incident radiation since W (work function) is constant for a given emitter. KE is directly proportional to $(\nu - \nu_o)$.
2. Keeping the frequency of incident radiation constant if the intensity of incident light is increased, more photons collide with more atoms and more photoelectrons are emitted. With the increase in the intensity of incident light photoelectric current increases.

   According to Einstein's equation, if the frequency of incident radiation is less than certain minimum value, the photoelectric emission is not possible. This frequency is known as threshold frequency or cut off frequency $(\nu_o)$. The wave length corresponding to this is known as threshold wavelength or cut-off wavelength. It is given by: $\lambda_o = 1/\nu_o$
3. Since Einstein treated photoelectric effect as a collision between a photon and an atom, he explained the instantaneous nature of photoelectric effect.

**Some other important points:**

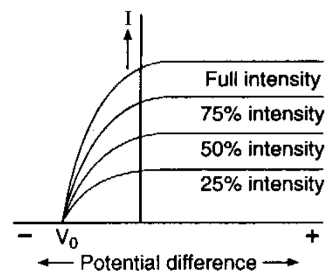
1. **Stopping potential:** The negative potential applied to the collector in order to prevent the electron from reaching the collector (i.e., to reduce the photoelectric current to zero) is known as stopping potential. If $V_o$ is the stopping potential the Einstein equation become $eV_o = ½ mv^2 = h\nu - W = h(\nu - \nu_o)$ quencies of incident radiation for a given emitter. The graph with the frequency on x-axis and stopping potential on y-axis is a straight line as shown in figure

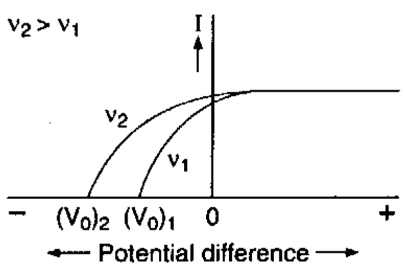



2. By the slope of the straight line (= h/e) value of Planck's constant is calculated.
3. The intercept of $V_o$ versus $\nu$ graph on frequency axis is equal to threshold frequency $(\nu_o)$. From this, the work function $(h\nu_o)$ can be calculated.

**Graphs in photoelectric effect:**

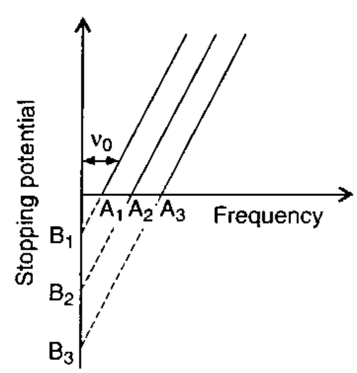
(a) **Photoelectric current versus potential difference graphs** for varying intensity (keeping same metal plate and same frequency of incident light): These graphs indicate that stopping potential is independent of the intensity of light and saturation current is directly proportional to the intensity of light




(b) **Photoelectric current versus potential difference graphs** for varying frequency (keeping same metal plate and same intensity of incident light): These graphs indicate that the stopping potential is constant for a given frequency. The stopping potential increases with increase of frequency. The KE of the emitted electrons is proportional to the frequency of incident light.

(c) **Stopping potential versus frequency graphs for different metals:** These graphs indicate that the slope is same for all metals, since they are parallel straight lines. The slope is a universal constant (=h/e). Further, the threshold frequency varies with emitter since the intercepts on frequency axis are different for different metals.





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## ATOMIC STRUCTURE AND SPECTRUM

### Rutherford's $\alpha$-particle scattering experiment

1. Most of the $\alpha$-particles came out of the gold foil without suffering any deviation from their straight line paths. This shows that the atom is hollow.
2. A few $\alpha$-particles collided with the atoms of the foil which are scattered or deflected through large angles. A very few particles even turned back towards the source itself.
3. Electrons cannot deflect the path of the $\alpha$-particles, i.e., electrons are very light particles,
4. Rutherford's model of the atom: According to this model;
   (a) the entire positive charge of the atom is concentrated in a small region near the center of the atom called nucleus.
   (b) the electrons revolve round the nucleus just like planets round the sun. The Coulomb force of attraction between the electron and the nucleus is equal to the centripetal force,
5. According to the classical electromagnetic theory, a revolving electron should radiate energy continuously and the electron should start spiralling and finally fall into the nucleus. This should lead to the destruction of the atom. As the energy decreases continuously the atom should give a continuous spectrum. Thus the Rutherford atom model failed to explain the formation of spectral lines and also failed to explain the stability of the atom.
6. According to Rutherford scattering formula, the number of $\alpha$-particles scattered at an angle $\theta$ by a target are given by:
   $N_\theta = \frac{N_o nt(2Ze^2)^2}{4(4\pi\varepsilon_o)^2 r^2 (mv_o)^2} \times \frac{1}{\sin^4 \frac{\theta}{2}}$ where $N_o$ = total number of particles that strike the unit area; n = number of target atoms per $m^3$; t = thickness of target; Ze = charge on the target nucleus; 2e = charge on a particle; r = distance of the screen from the target; $v_o$ = velocity of a particle at nearest distance of approach.
7. The size of the nucleus or the distance of closest approach is given by: $r_o = \frac{1}{4\pi\varepsilon_o} \times \frac{(2Ze)^2}{\frac{1}{2}mv_o^2}$

### Bohr's atom model

Bohr modified Rutherford's atom model on the basis of quantum theory of radiation. His model is based on the following three postulates:

1. **First postulate:** Electron revolves round the nucleus just like a planet round the sun. The coulomb's force of attraction between the electron and the nucleus is equal to the centripetal force. i.e. $\frac{mv^2}{r} = \frac{1}{4\pi\varepsilon_o} \times \frac{(Ze)(e)}{r^2}$
2. **Second postulate:** Electrons cannot revolve in all those orbits as suggested by classical theory, but only in those orbits for which the angular momentum is equal to an integral multiple of $h/2\pi$. Thus $I\omega = mvr = \frac{nh}{2\pi}$
   (a). The SI unit of Planck's constant (h) is joule-sec and its value is equal to 6.63 x $10^{-34}$ joule-sec.
   (b). As long as the electron revolves in these orbits, it neither loses energy nor gains energy. These orbits are known as stationary orbits.
3. **Third postulate:** When an electron jumps from higher energy level to lower energy level, the energy difference is radiated in the form of light of frequency $\nu$, i.e. $E_2 - E_1 = h\nu$

### Radius of the orbit

1. **Radius of the $n^{th}$ orbit** of Hydrogen like atom **($r_n$)** $= \frac{\varepsilon_o n^2 h^2}{\pi m Z e^2}$ (Hydrogen like atoms are those which have only one electron and whose atomic number Z > 1). Radius of the first Bohr orbit of hydrogen atom $= \frac{\varepsilon_o h^2}{\pi m e^2}$ = 0.53 x $10^{-10}$ m
2. **Radius of any Bohr's orbit** of any hydrogen like atom **($r_n$)** $= \frac{r_1 n^2}{Z} = \frac{0.53 \times 10^{-10} n^2}{Z}$ m



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**Velocity of the electron in the orbit**

1. **Velocity of the electron in $n^{th}$ orbit** of any atom $(\mathbf{v_n}) = \frac{Ze^2}{2\varepsilon_o nh}$. Velocity of the electron in the first Bohr orbit of hydrogen atom $= \frac{e^2}{2\varepsilon_o h} = 2.19\times10^6\ m/s = \frac{c}{137}$ where c is the velocity of light.
2. Velocity of the electron in any orbit of any atom $(v_n) = \frac{Zv_1}{n} = \frac{Z\times2.19\times10^6}{n}$ m/sec
3. Velocity of the electron is inversely proportional to the square root of the radius of the orbit, i.e., $v_n \propto \sqrt{1/r}$

**Energy of the electron in an orbit**

1. **Kinetic energy** of the electron in an orbit $= \frac{1}{2}mv^2 = \frac{Ze^2}{8\pi\varepsilon_o r}$
2. **Potential energy** of the electron in an orbit $= -\frac{Ze^2}{4\pi\varepsilon_o r} = -2(KE)$.
3. **Total energy** of the electron in an orbit = PE + KE $= -\frac{Ze^2}{4\pi\varepsilon_o r} + \frac{Ze^2}{8\pi\varepsilon_o r} = -\frac{Ze^2}{8\pi\varepsilon_o r} = -KE$
4. **$E_n$ = Total energy of electron in $n^{th}$ orbit** of any hydrogen-like atom $= -\frac{13.6Z^2}{n^2}$ eV
5. In case of hydrogen atom, Z = 1; so $E_n = -\frac{13.6}{n^2}$ eV

**Dependence of T, ν, ω, L, v, KE, PE, TE and r on principal quantum number n**

1. $T \propto n^3$, i.e., time period of revolution is directly proportional to the cube of the principal quantum number.
2. Frequency of revolution $\nu = 1/T$ . Hence, $\nu \propto 1/n^3$ , i.e., frequency of revolution of the electron is inversely proportional to the cube of the principal quantum number.
3. Angular velocity or angular frequency $\omega = 2\pi\nu$. Hence, $\omega \propto 1/n^3$
4. Angular momentum, $L = nh/2\pi$, i.e. angular momentum is directly proportional to the principal quantum number.

**Frequency of radiation emitted:** Frequency of radiation emitted

$$\nu = \frac{E_2 - E_1}{h} = \frac{13.6Z^2}{h}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] = \frac{10^{16}}{3}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]Z^2$$

For Hydrogen atom $\nu = \frac{10^{16}}{3}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$

**Wave number of radiation emitted :** $\nu = \frac{c}{\lambda} = \frac{13.6Z^2}{h}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ and wave number $\bar{\nu} = \frac{1}{\lambda} = \frac{13.6Z^2}{hc}\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ also wave number $\bar{\nu} = \frac{1}{\lambda} = RZ^2\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$ ($\therefore Rhc = 13.6$) Where R is the Rydberg constant and is equal to $1.095 \times 10^7\ m^{-1}$

**Spectral series of hydrogen atom:**

**(i) Lyman series:**

(a) For this series $n_1 = 1$, $n_2 = 2, 3, 4, ...$
(b) This series lies in the ultraviolet region.
(c) The first member of the Lyman series is given by; $\lambda = 4/3R$
(d) The last member of the Lyman series is given by; $\lambda = 1/R$
(e)



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**(ii) Balmer series:**

(a) For this series $n_1 = 2$, $n_2 = 3, 4, 5, ...$

(b) This series lies in visible part of spectrum.

(c) The first member of the Balmer series is given by; $\lambda = 36/5R$

(d) The last member of the Balmer series is given by; $\lambda = 4/R$

**(iii) Paschen series:**

(a) For this series $n_1 = 3$, $n_2 = 4, 5, 6, ...$

(b) This series lies in near infrared region.

(c) The first member of the Paschen series is given by; $\lambda = 144/7R$

(c) The last member of the Paschen series is given by; $\lambda = 9/R$

**(iv) Brackett series:**

(a) For this series $n_1 = 4$, $n_2 = 5, 6, 7, ...$

(b) This series lies in infrared region.

(c) The first member of the Brackett series is given by; $\lambda = 16 \times 25/9R$

(d) The last member of the Brackett series is given by; $\lambda = 16/R$

**(v) Pfund series:**

(a) For this series $n_1 = 5$, $n_2 = 6, 7, 8, ...$

(b) This series lies in infrared region.

(c) The first member of the Pfund series is given by; $\lambda = 25 \times 36/11R$

(d) The last member of the Brackett series is given by; $\lambda = 25/R$

**Some important points:**

1. The ground state energy of the hydrogen atom is taken as the unit of energy in atomic physics. It is known as Rydberg (1 Rydberg = 13.6 eV).
2. The negative sign appearing in the expression for energy indicates that the electron does not have enough energy to escape from the nucleus. Energy is required to remove the electron from the influence of the nucleus.
3. As the value of n increases, though the numerical value of energy decreases but its actual value increases because of the negative sign. Thus the energy of the outer orbit is more than the energy of the inner orbit,
4. In the limit $n = \infty$, $E = 0$ and the electron is no longer bound to the nucleus to form an atom.
5. The energies specified by the above expression for energy are called energy levels of the hydrogen atom.
6. **Excitation:** It is the process of raising an electron within an atom from a lower energy state to a higher energy state.
7. **Excited state:** The state of an atom when an electron has been raised to a higher orbit than it occupies in the ground state, is called an excited state.
8. **Ground state:** The lowest energy state of an atom when the atom is most stable, is called ground state.
9. **Ionisation:** If during the process of excitation the electron is completely removed from the atom, the atom is said to be ionised. The process of removal of the electron from an atom is called ionisation.
10. **Ionisation energy:** The energy required to remove an electron from an atom is called ionisation energy. The ionisation energy required to ionise a hydrogen atom is = 13.6 eV.
11. **Ionisation potential:** The potential difference through which an electron is moved to gain ionisation energy is called ionisation potential. The ionisation potential of hydrogen atom is 13.6 volt.

**Types of spectra:** Spectra are mainly of two kinds, emission spectrum and absorption spectrum.

1. **Emission spectrum:** When light from an incandescent source is made to fall on the slit of a spectrometer, then we see an emission spectrum of the source. **Emission spectrum is of three types:**

   (a). **Line spectrum:** It is given by incandescent vapours or gases in atomic state. It is on account of the individual behaviour of atoms. Line spectrum is characteristic of the element. No two different elements give identical line spectra.

   (b). **Band spectrum:** It is given by incandescent vapours or gases in molecular state. It is on account of the individual behaviour of molecules. Band spectrum is the characteristic of the compound. No two different compounds give identical band spectra.

   (c). **Continuous spectrum:** It is given by incandescent solids and liquids. It is on account of the collective behaviour of atoms or molecules.





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2. **Absorption spectrum:** When white light from an incandescent source passes through transparent gas, liquid or solid at a lower temperature before falling on the slit of the spectrometer, then we see an absorption spectrum.
   **Absorption spectrum is also of three types:**
   (a) For line absorption, the transparent absorbing material must be in the form of atomic vapours or gas.
   (b) For band absorption, the absorbing material must be in the form of molecular vapours or gas.
   (c) For continuous absorption, the transparent absorbing material must be a solid or a liquid.
3. In general, the number of emission lines is larger than the absorption lines.
4. For n levels, the number of possible emission lines = $n(n - 1)/2$ and the number of possible absorption lines = $(n - 1)$.
5. **Fraunhofer lines:** These are the dark lines observed in the solar spectrum. These dark lines were discovered by Wolaston. When white light from the photosphere passes through the chromosphere which contains vapours in atomic state, these vapours absorb the light of those wavelengths which they themselves would emit when being incandescent.

## Nucleus & Nuclear Energy

**Nucleus and its constituents:**
1. Nucleus of an atom is positively charged. Its radius is of the order of $10^{-15}$ metre.
2. Mass of proton is $m_p = 1.67208 \times 10^{-27}$kg = 1.00728 amu. (Atomic mass unit), 1 amu is equal to $(l/12)_{th}$ the mass of the carbon nucleus i.e. 1 amu = $1.67 \times 10^{-27}$ kg
3. Mass of neutron is $m_n = 1.67431 \times 10^{-27}$ kg = 1.008665 amu.
4. The radius of the nucleus is given by: $R = R_o A^{1/3}$, where $R_o$ = 1.1 fermi i.e. $1.1 \times 10^{-15}$ m and A is the mass number.
5. Density of nuclear matter is constant and is equal of the order of $10^{17}$kg/m$^3$ and is independent of the mass number.

**Types of nuclei:**
1. **Isotopes:** Isotopes are the nuclei with the same atomic number Z but different mass numbers A. Isotopes are atoms of the same element and have same physical and chemical properties. If the relative abundance of isotopes in an element has a ratio $n_1 : n_2$ whose atomic masses are $m_1$ and $m_2$, then atomic mass of the element is $M = \frac{n_1 m_1 + n_2 m_2}{n_1 + n_2}$
2. **Isobars:** Isobars are the nuclei with the same mass number A but different atomic number Z. The isobars are the atoms of different elements and have different physical and chemical properties.
3. **Isotones:** Isotones have the same neutron number but different atomic number and mass number. The isotones are atoms of different elements and have different physical and chemical properties.
4. **Isomers:** Isomers have the same atomic number and same mass number but their nuclei exist in different energy states. These nuclei are distinguished by their different life times.
5. **Mirror nuclei:** Nuclei, having the same mass number A but with the proton and neutron number interchanged are called mirror nuclei.

**Forces between nucleons:**

**1. Electrostatic coulombic forces:**
   (a) The coulombic forces exist between protons only.
   (b) As the atomic number increases, the size of the nucleus increases and therefore the coulombic forces increase.
   (c) These forces cause instability of the nucleus.

**2. Nuclear forces:**
   (a) These forces exist between any two nucleons and are the strongest known forces in nature.
   (b) These are attractive forces, non central forces and cause stability of the nucleus.
   (c) Nuclear forces are short-range forces. These do not exist at large distances greater than one fermi.
   (d) According to Yukawa these forces can be treated as exchange forces. $\pi^+$ $\pi^-$ $\pi^0$ mesons are the particles which continuously exchange between proton and proton or neutron and neutron or a proton and a neutron.
   (e) These forces show saturation properties and are spin dependent.

**3. Hard core forces:**
   (a) These are repulsive forces.
   (b) These forces come into existence when the distance between the nucleons is 0.5 fermi.
   (c) Due to these forces the density of the nucleus remains constant.


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4. **Tensor forces:**
   (a) These forces are due to spinning of nucleus.
   (b) A spinning nucleus behaves like a magnetic dipole. There exists a force between two dipoles. This force is called tensor force, which prevails up to a distance of 3 fermi.

**Stability of nucleus:**
1. The nucleus is more stable when the number of protons is equal to the number of neutrons.
2. The nuclei having even number of protons or even number of neutrons are more stable.
3. If number of protons or number of neutrons in a nucleus is equal to one of the magic numbers, then the nucleus is stable. Magic numbers are 2, 8, 14, 20, 28, 50, 82 and 126.

**Mass energy equivalence:**
1. Energy is released in the form of $\gamma$-rays of frequency $\nu$ given by: $E = mc^2 = h\nu$.
2. The amount of energy equivalent to 1 amu is 931 MeV.
3. The amount of energy released when an electron is annihilated is 0.51 MeV.

**Mass defect:**
1. The actual mass of the nucleus is always less than the sum of the masses of its constituent particles in free state. This difference in mass is known as mass defect.
2. Mass defect $\Delta m = [Zm_p + (A - Z)m_n] - M_N$, where $m_p$ = mass of proton, $m_n$ = mass of the neutron and $M_N$ = actual mass of the nucleus.
3. Mass defect per nucleon is called packing fraction.

**Binding energy:**
1. The energy equivalent of mass defect of a nucleus is called the binding energy of the nucleus.
2. If $\Delta m$ is the mass defect in amu, then binding energy = $\Delta m$ x 931 MeV.
3. If $\Delta m$ is expressed in kg, then binding energy = $\Delta mc^2$.
4. In order to break the nucleus into its constituent particles, the same amount of energy (= binding energy) is required.

**Variation of binding energy per nucleon with mass number:**
1. The binding energy per nucleon (except for $He^4$, $C^{12}$ and $O^{16}$) rises first sharply and reaches a maximum value 8.8 MeV in the neighbourhood of A = 50.
2. After A = 50, the curve falls very slowly and reaches a value of 8.4 MeV at about A = 140. For higher mass number, the energy decreases to about 7.6 MeV (for A = 240).
3. Binding energy per nucleon is a measure of stability of nucleus. Greater the binding energy, greater is stability of atom.
4. Binding energy per nucleon is more for medium nuclei than for heavy nuclei. Hence, medium nuclei are very highly stable.

**Fission:**
1. The splitting of the heavy nucleus into two medium nuclei is known as nuclear fission.
2. The reaction representing the basic fission process of uranium nucleus is written as follows:
   $_{92}U^{235} + {}_0n^1 \rightarrow {}_{92}U^{236} \rightarrow X + Y +$ neutrons
   Here, $_{92}U^{236}$ is a highly unstable isotope and X and Y are the fission fragments.
3. $U^{235}$ is more easily fissionable than $U^{238}$. Fast neutrons ( energy > 1MeV) are required for the fission of $U^{238}$ while slow neutrons (energy = 0.025 eV) are needed for the fission of $U^{235}$. Naturally available uranium has 0.714% of $U^{235}$, 0.006% of $U^{235}$ and 99.28% of $U^{238}$.
4. Easily fissionable element is plutonium, $_{94}Pu^{239}$, which is an artificially formed element.
5. The energy released in the fission of one $U^{235}$ atom is about 200 MeV .

**Chain reaction:**
1. A chain reaction is a self-propagating process in which a number of neutrons multiply rapidly during fission till the whole of the fissile material is disintegrated.
2. To start a chain reaction a minimum mass of fissile material is required. This mass is called critical mass or critical size.
3. Uncontrolled chain reaction is the principle of atom bomb and controlled chain reaction is principle of nuclear reactor.

**Nuclear reactor:**
1. A nuclear reactor consists of five main elements:
   (a). **Fuel:** The commonly, used fuels are isotopes of uranium, $U^{233}$, $U^{235}$; isotopes of thorium, $Th^{232}$; isotopes of plutonium, $Pu^{239}$, $Pu^{240}$ and $Pu^{241}$.
   (b). **Moderator:** Moderator slows down the highly energetic neutrons. Examples: Heavy water, graphite, beryllium.
   (c). **Control rods:** The function of control rods is to absorb the excess of neutrons and thus controls the chain reaction. Examples: cadmium rods, boron rods.


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(d). **Neutron reflector:** This prevents the leakage of neutrons. Materials of high scattering cross-section and low absorption cross-section are good reflectors,

(e). **Coolants:** The cooling system removes the heat evolved in the reactor core. Examples: ordinary water, heavy water, helium, CO;, liquid sodium, potassium, mercury, etc.

2. **Breeder reactor:** In a breeder reactor more nuclear fuel would be produced than consumed. In this reactor non-fissionable $U^{238}$ is converted into fissionable $Pu^{239}$.
3. **Power of a reactor:** If n atoms undergo fission in a time t seconds and E be the energy released in each fission, then power P = (nE/t).

**Nuclear fusion:**

1. Fusion is a process in which lighter nuclei combine to form a heavy nucleus. When two deuterium nuclei are fused together, a single helium nucleus is formed. ${}_1H^2 + {}_1H^2 \rightarrow {}_2He^4 + 24MeV$
2. For fusion very high temperature ($10^7$ to $10^8$ K) is required and so the reaction is called thermonuclear reaction.
3. Fusion energy is greater than fission energy.

**Stellar energy:**

1. The source of solar energy or stellar energy is nuclear fission. The solar energy is due to formation of helium by the combination of hydrogen nuclei by fusion reaction.
2. The light elements hydrogen and helium together form about 99% by weight of the sun's matter.
3. The sun radiates 3.8 x $10^{26}$ joules of energy in each second.
4. Hydrogen bomb is based on the principle of nuclear fission.

## RADIOACTIVITY

**Introduction:**

1. All the elements with atomic number greater than 82 are naturally radioactive.
2. The radioactivity may be defined as the spontaneous disintegration of the atoms of heavy elements with the emission of $\alpha$-particles, $\beta$-particles and $\gamma$-rays.
3. Rate of disintegration of radioactive elements is not affected by the external conditions of temperature, pressure, electric or magnetic fields.
4. A particular radioactive element can emit either $\alpha$-particle or $\beta$-particle but never both. However, $\gamma$-rays can be emitted by $\alpha$-emitter or by $\beta$-emitter or $\gamma$-emitter.
5. The conversion of lighter elements into radioactive elements by the bombardment of fast moving particles is called artificial or induced radioactivity.
6. The $\beta$-particle is the electron ejected from the nucleus but not from the orbits of an atom. The neutron in the nucleus decays into proton and an electron.

**Radioactive displacement law:** It was discovered by Soddy and Fajans. According to this law:

1. In all radioactive transformations either an $\alpha$ or a $\beta$-particle (never both or more than one of each kind) is emitted.
2. When a radioactive element (X) decays through the emission of an $\alpha$-particle, a new atom (Y) is formed given by
$$ {}_Z X^A \rightarrow {}_2 He^4 + {}_{Z-2} Y^{A-4} $$
3. When a radioactive element (X) decays through the emission of a $\beta$-particle, a new atom (Y) is formed given by
$$ {}_Z X^A \rightarrow {}_{-1} e^0 + {}_{Z+1} Y^A $$
4. When a radioactive element decays through the emission of $\gamma$-rays, neither atomic number nor the mass number changes. By the emission of $\alpha$-particle or $\beta$-particle the nucleus is left in the excited state. This excited nucleus emits $\gamma$-rays and tries to reach the ground state.

**Law of radioactive disintegration:** If N is the number of atoms present at a given instant t, then the rate of disintegration is proportional to N, i.e., $\frac{dN}{dt} = -\lambda N$ where $\lambda$ is called as the disintegration constant or decay constant. If $N_o$ is the initial number of atoms present, then $N = N_o e^{-\lambda t}$

**Activity of a radioactive substance:** The number of disintegrations in one second is called activity. This is denoted by R and at any instance when N number of atoms are undecayed is given by $R = \lambda N$. If $R_o$ is the initial activity then $R = R_o e^{-\lambda t}$

**Half-life (T) :** Half-life period (T) of a radioactive element is defined as the time taken by the element to reduce to half of its initial amount and is given by $T = \frac{0.693}{\lambda}$

**Aaverage life ($T_{av}$) :** Average life or mean life $T_{av} = \frac{\text{sum of life times of all atoms}}{\text{total no. of atoms}}$ or $T_{av} = \frac{1}{\lambda}$

$T = 0.6937\, T_{av.}$ or $T_{av.} = 1.44T$

**Some important points:**

1. If N is the number of atoms left undecayed after 'n' half-lives, then $\frac{N}{N_o} = \left(\frac{1}{2}\right)^n$ where $N_o$ is the initial number of atoms.
2. If $M_o$ be the initial mass and M is the undecayed mass left after 'n' half-lives, then $\frac{M}{M_o} = \left(\frac{1}{2}\right)^n$
3. If $A_o$ be the initial activity and A is the activity after 'n' half-lives, then $\frac{A}{A_o} = \left(\frac{1}{2}\right)^n$

**Radioactive equilibrium:** In a radioactive series at the stable equilibrium, the rate of decay of any radioactive product is just equal to its rate of production from the previous member of the series.

**Units of radioactivity:**

(a) The SI unit of radioactivity is Becquerel (bq). 1 becquerel = 1 disintegration/sec or 1 dps

(b) 1 curie or 1 Ci = $3.7 \times 10^{10}$ dps = $3.7 \times 10^{10}$ bq

(c) 1 rutherford or 1 Rd = $10^6$ dps = $10^6$ bq

## X-RAYS

**(NOT INCLUDED IN ANY CBSE ENTRANCE EXAM)**

**X – Rays :** When fast moving electrons strike a target of suitable material (having high atomic weight and high melting point), X-rays are produced.

1. X-rays are electromagnetic waves of very small wavelength ranging from 100 to 0.1 angstrom.
2. They undergo reflection, refraction, interference, diffraction and polarization but they are not deviated by prisms or lenses.
3. They produce illumination on falling on fluorescent materials and affect photographic plates.
4. They ionise the gases through which they pass.
5. They penetrate through different depths into different substances, e.g., wood, thin metal sheets, etc., depending upon their wavelength.
6. They do not pass through heavy metals and bones.
7. They are very active and may eject photoelectrons from metals (show photoelectric effect).
8. They can be used to detect possible cracks, air cavities and other flaws in the interior of metal castings.

**Intensity control in X-ray tube:** Intensity implies the number of X-ray photons produced from the target. The intensity of X-rays is proportional to the number of electrons emitted per sec from the filament and this can be increased by increasing the filament current in the Coolidge tube.





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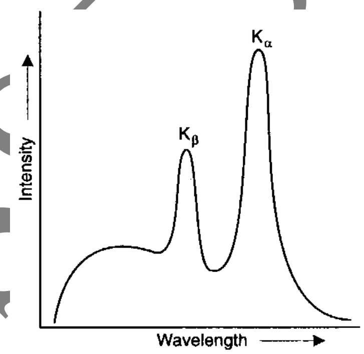
**Quality control in X-ray tube:** Quality of X-rays implies the penetrating power of X-rays. Penetrating power is proportional to the potential difference between the filament and target. The quality of X-rays can be controlled by varying the potential difference between the cathode and the target. Depending on the penetrating power. X-rays are of two types:

a. **Soft X-rays:** X-rays having wavelength of 4 angstrom or above are called soft X-rays due to their low penetrating power.

b. **Hard X-rays:** X-rays having low wavelength of the order of 1 angstrom have high frequency and are called hard X-rays due to their high penetrating power.

**Continuous X-rays:**

1. Continuous X-rays are produced due to retardation of high speed electrons while passing through the strong electric field of the nucleus.
2. When the electron loses whole of its energy in a single collision with the atom, an X-ray photon of maximum energy $h\nu_{max}$ is emitted, i.e., $h\nu_{max} = eV$ or $\nu_{max} = eV/h$
3. Minimum wavelength $\lambda_{min.} = c / \nu_{max} = hc / eV$. This equation shows that minimum wavelength $\lambda_{min.}$ is inversely proportional to the accelerating potential (V). With the increase of applied voltage, the minimum wavelength decreases.
4. Each spectrum abruptly ends at a certain minimum wavelength or maximum frequency. This minimum wavelength is called the limiting wavelength.
5. The maximum intensity of continuous X-rays increases with the increase of applied voltage.
6. If a graph is plotted between accelerating potential (V) and maximum frequency ($\nu_{max}$) of a continuous X-ray spectrum, a straight line passing through origin is obtained.
7. The slope of the straight line is given by **e / h** from which Planck's constant can be calculated.
8. Continuous X-ray spectrum is independent of the material of the target.
9. Photoelectric effect is the reverse process of the production of continuous X-ray spectrum.




**Characteristic X-ray spectrum:**

1. Characteristic X-ray spectrum is produced when high-energy electrons knock out the electrons from the innermost shells K, L or M of the atoms of the target element.
2. Different atoms (elements) emit different characteristic spectra.
3. These X-rays have discrete energy or a particular wavelength. These particular wavelengths are the characteristic nature of the target.
4. The number of lines present in the Characteristics X-ray spectrum depends on the element as well as the acceleration potential.
5. The transition of electron: (K series)
   a. from 2nd orbit to 1st orbit forms $K_\alpha$ line
   b. from 3rd orbit to 1st orbit forms $K_\beta$ line
   c. from 4th orbit to 1st orbit forms $K_\gamma$ line
6. Similarly, the transitions from 3rd, 4th, 5th, etc., to 2nd orbit correspond to $L_\alpha$, $L_\beta$, $L_\gamma$……….lines known as L-series.
7. The wavelength of $K_\alpha$ line is $\frac{1}{\lambda_{K_\alpha}} = R(Z-1)^2\left(\frac{1}{1^2}-\frac{1}{2^2}\right) = R(Z-1)^2 \times \frac{3}{4}$ or $\lambda_{K_\alpha} = \frac{4}{3R(Z-1)^2}$
8. The heaviest elements such as uranium, thorium emit a complete spectrum where all the series K, L, M, N are present.

**Moseley's law:**

1. The square root of the frequency of the characteristic X-ray spectrum line is proportional to the atomic number

$$\sqrt{\nu} \propto Z \quad \text{or} \quad \sqrt{\nu} = a(Z-b)$$

2. The graph plotted between the atomic number (Z) and square root of frequency (W) is a straight line making a positive intercept on x – axis. The slope of straight line gives the constant a while the intercept on x – axis provides the value of b. For K – series X-rays the value of constant b = 1.
3. X-ray spectra cannot be obtained with very light elements like hydrogen.
4. X-ray spectra are not found in the solar spectrum.
5. Moseley's law helps to determine the relative positions of several elements in the periodic table and helps in the prediction and discovery of new elements.

## Modern Physics Assignment

1. If 5% of the energy supplied to a bulb is radiated as visible light, the number of visible quanta emitted per second by a 100 W bulb, assuming the wavelength of visible light to be 5.6 X $10^{-5}$ cm, is
(a) 1.4 x $10^{19}$ (b) 1.4 x $10^{20}$ (c) 2 x $10^{19}$ (d) 2 x $10^{20}$
2. The work function of a metal in 4 eV. For the emission of photoelectrons of zero velocity from the metal surface, the wavelength of the incident radiation should be
(a) 1700 Å (b) 2700 Å (c) 3100 Å (d) 5900 Å
3. The threshold wavelength for a photo-sensitive surface is 6000 Å and the wavelength of incident light is 5000 Å. Then the maximum energy of emitted electrons would be
(a) 0.041 eV (b) 0.41 eV (c) 4.1 eV (d) 41 eV
4. The work function of a metallic surface is 5.01 eV. Photoelectrons are emitted when light of wavelength 2000 Å falls on it. The potential difference required to stop fastest photoelectrons is ($h$ = 4.14 x $10^{-15}$ eV)
(a) 1.2 V (b) 2.4 V (c) 3.6 V (d) 4.8 V
5. The momentum of a photon of frequency $\nu$ is
(a) $h\nu/c^2$ (b) $h\nu/c$ (c) $h\nu c$ (d) $h\nu c^2$
6. A photocell is illuminated by a small bright source placed 1 m away. When the same source of light is placed 2 m away, electrons emitted by cathode
(a) carry one quarter of their previous energy
(b) carry one quarter of their previous momenta
(c) are half as numerous
(d) are one-quarter as numerous.
7. Light of two different frequencies whose photons have energies 1 eV and 2.5 eV successively illuminate a metal of work function 0.5 eV. The ratio of the maximum speeds of the emitted electrons will be
(a) 1 : 5 (b) 1 : 4 (c) 1 : 2 (d) 1 : I
8. When a metallic surface is illuminated by a monochromatic light of wavelength $\lambda$, the stopping potential for photoelectric current is $3V_0$. When the same surface is illuminated by light of wavelength $2\lambda$, the stopping potential is $V_0$. The threshold wavelength for this surface for photoelectric effect is
(a) 6 $\lambda$ (b) $4\lambda/3$ (c) $4\lambda$ (d) $8\lambda$
9. In photoelectric emission the number of electrons ejected per second is proportional to the
(a) intensity of light (b) wavelength of light
(c) frequency of light (d) work function
10. A photon of wavelength 1000 Å has energy 12.3eV. If light of wavelength 5000 Å, having intensity $I$, falls on a metal surface, the saturation current is 0.40μA and the stopping potential is 1.36 V. The work function of the metal is
(a) 2.47 eV (b) 1.36eV (c) 1.10 eV (d) 0.43 eV.
11. In above Q. if the intensity of light is made $4I$, the saturation current (in μA) will become
(a) 0.4 (b) 0.4 x 2 (c) 0.4 x 4 (d) 0.4 x 16
12. When radiation of wavelength 3000 Å is incident on a photosensitive surface the stopping potential of electrons is 2.5 V. The stopping potential for radiation of wavelength 1500 Å will be
(a) 2.5 V (b) 5.0 V (c) more than 5.0 V
(d) less than 5.0 V but more than 2.5 V
13. Of the following, the one which has the largest de Broglie wavelength for the lame speed is
(a) electron (b) proton (c) $\alpha$-panicle (d) oxygen atom
14. A proton and an $\alpha$-particle are accelerated through the same potential difference. The ratio of their de Broglie wavelengths is
(a) $\sqrt{2}$ (b) $l/\sqrt{2}$ (c) $2\sqrt{2}$ (d) 2
15. The concept of the nuclear atom was established from experiments on the
(a) emission of electrons from metal surfaces
(b) scattering of $\alpha$-particles by metal foils
(c) diffraction of electrons by crystals
(d) discharge of electricity through gases.
16. Rutherford's model of the atom accounts for the
(a) scattering of $\alpha$-particles by metal foils
(b) stability of electron orbits
(c) stability of nuclei (d) line spectra of elements.
17. Which of the following quantities will be zero for $\alpha$-particles at the point of closest approach to the gold nucleus in Rutherford's scattering experiment ?
(a) acceleration (b) kinetic energy





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(c) potential energy (d) none of the above.

18. The mass number of a nucleus is
    (a) always less than its atomic number
    (b) always more than its atomic number
    (c) sometimes equal to its atomic number
    (d) None of these
19. In stable nuclei, the number of neutrons (N) is related to the number of protons (Z) as
    (a) $N < Z$ (b) $N = Z$ (c) $N > Z$ (d) $N \geq Z$
20. An $\alpha$-particle of energy 5 MeV is scattered through 180° by a fixed uranium nucleus. The distance of closed approach is of the order of
    (a) 1 Å (b) $10^{-10}$ cm (c) $10^{-12}$ cm (d) $10^{-15}$ cm
21. The radius of a nucleus with mass number 16 is 3 fm. The radius of another nucleus of mass number 128 is
    (a) 6 fm (b) 12 fm (c) 18 fm (d) 24 fm
22. The nuclei ${}_6C^{13}$ and ${}_7N^{14}$ can be described as
    (a) Isobars (b) isotones
    (c) isotopes of carbon (d) isotopes of nitrogen
23. The average binding energy of a nucleon inside an atomic nucleus is about
    (a) 8 eV (b) 8 MeV (c) 8 J (d) 8 ergs.
24. An atomic nucleus has mass
    (a) less than the total mass of their constituent protons and neutrons
    (b) equal to the total mass of their constituent protons and neutrons
    (c) more than die total mass of their constituent protons and neutrons
    (d) sometimes more and sometimes less than the total mass of their constituent protons and neutrons.
25. sThe binding energy per nucleon for deuteron ${}_1H^2$ and helium ${}_2He^4$ are 1.1 MeV and 7.0 MeV. The energy released when two deuterons fuse to form a helium nucleus is (in MeV)
    (a) 2.2 (b) 23.6 (c) 28.0 (d) 30.2
26. A nuclide with mass number *m* and atomic number *n* disintegrates emitting an $\alpha$-particle and a negative $\beta$-particle. The resulting nuclide has mass number and atomic number respectively equal to
    (a) m-4, n-2 (b) m-2, n (c) m-2, n+1(d) n-4, n-1
27. A nuclide of mass number A and atomic number Z emits a $\beta$-particle. The mass number and atomic number of the resulting nuclide are, respectively
    (a) A, Z (b) A + 1, Z (c) A, Z + 1 (d) A – 4, Z – 2
28. The radioactive nuclide ${}^{228}_{88}\mathrm{Ra}$ decays by the emission of three $\alpha$-particles and one $\beta^-$particle. The nuclide X finally formed is
    (a) ${}^{220}_{84}\mathrm{X}$ (b) ${}^{222}_{86}\mathrm{X}$ (c) ${}^{216}_{83}\mathrm{X}$ (d) ${}^{215}_{88}\mathrm{X}$
29. The end product of the decay of ${}^{232}_{90}\mathrm{Th}$ is ${}^{208}_{82}\mathrm{Pb}$. The number of $\alpha$ and $\beta$ particles emitted are,
    (a) 3, 3 (b) 6, 4 (c) 6, 0 (d) 4, 6
30. One-eighth of the initial mass of a certain radioactive isotope remains undecayed after one hour. The half life of the isotope in minutes is
    (a) 8 (b) 20 (c) 30 (d) 45.
31. The half life of radium is 1600 years. The fraction of a sample of radium that would remain undecayed after 6400 years is
    (a) 1/2 (b) ¼ (c) 1/8 (d) 1/16
32. The decay constant of a radioactive sample is $\lambda$. The half life and mean life of the sample are respectively given by
    (a) $1/\lambda$ and (log 2)/ $\lambda$ (b) (log2)/ $\lambda$ and $1/\lambda$
    (c) $\lambda$ (log2) and $1/\lambda$ (d) $\lambda$/(log2) and $l/\lambda$
33. The probability of a radioactive atom to survive 5 times longer than its half life period is
    (a) 2/5 (b) 2 x 5 (c) $2^{-5}$ (d) $2^5$
34. A radioactive isotope X with a half life of 1.37 x $10^9$ years decays to Y which is stable. A sample of rocks from the moon was found to contain both X and Y in the ratio 1 : 7. The age of the rocks is
    (a) 1.96 x $10^8$ years (b) 3.85 x $10^9$ years
    (c) 4.11 x $10^9$ years (d) 9.59 x $10^9$ years
35. An accident occurs in a laboratory in which a large amount of a radioactive material, having a half life of 20 days, becomes embedded in the floor and walls so that the level of radiation is 32 times the permissible level. The laboratory can be safely occupied after
    (a) 20 days (b) 32 days (c) 64 days (d) 100 days
36. In the transformation sequence represented by ${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y \rightarrow {}^{A-4}_{Z-2}Y \rightarrow {}^{A-4}_{Z-1}K$, the decays are in order
    (a) $\alpha, \beta, \gamma$ (b) $\beta, \gamma, \beta$ (c) $\gamma, \alpha, \beta$ (d) $\alpha, \gamma, \beta$
37. Two radioactive substances A and B have half lives of T and 2T respectively. Samples of A and B contain equal number of nuclei initially. After a time 4T, the ratio of the number of undecayed nuclei of A to the number of undecayed nuclei of B is
    (a) 1 : 4 (b) 1 : 2 (c) 2 : 1 (d) 4 : 1
38. A radioactive sample with a half-life of 1 month has activity 2 $\mu$Ci. Its activity 2 months earlier was
    (a) 1 $\mu$Ci (b) 0.5 $\mu$Ci (c) 4 $\mu$Ci (d) 8 $\mu$Ci
39. Two radioactive substances X and Y initially contain equal number of nuclei. X has a half life of 1 hour and Y has a half life of 2 hours. After 2 hours the ratio of the activity of X to that of Y is
    (a) 1 : 4 (b) 1 : 2 (c) 1 : 1 (d) 2 : 1
40. The counting rate observed from a radioactive source at t = 0 was 1600 counts/s and at t = 8s it was 100 counts/s. The counting rate observed at t = 6 s was
    (a) 400 (b) 300 (c) 200 (d) 150
41. Consider a radioactive material of half life 1.0 minute. If one of the nuclei decays now, the next one will decay after
    (a) 1.0 minute (b) 1/$\log_e$ 2 minutes (c) any time.



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(d) 1/N minutes where N is the number of nuclei present at that moment

42. In a β-decay
    (a) the parent and the daughter nuclei have the same number of protons
    (b) the daughter nucleus has one protonless than the parent nucleus
    (c) the daughter nucleus has one proton more than the parent nucleus
    (d) the daughter nucleus has one neutron more than the parent nucleus.
43. Which of the following is a fusion reaction ?
    (a) ${}_1^2H+{}_1^2H \rightarrow {}_2^4 He$ (b) ${}_0^1n+{}_7^{14}N \rightarrow {}_6^{14} C+{}_1^1H$
    (c) ${}_0^1n+{}_{92}^{238}U \rightarrow {}_{93}^{239} Np + \beta^- + \gamma$
    (d) ${}_1^3H \rightarrow {}_2^3 He + \beta^- + \gamma$
44. Boron has two isotopes ${}_5^{10}B$ and ${}_5^{11}B$. If the atomic weight of Boron is 10.81, the ratio of ${}_5^{10}B$ and ${}_5^{11}B$ in nature is
    (a) 19/81 (b) 20/53 (c) 15/16 (d) 10/11.
45. When ${}_{92}^{235}U$ undergoes fission, 0.1% of its original mass is changed into energy. How much energy is released if 1 kg of ${}_{92}^{235}U$ undergoes fission ?
    (a) $9 \times 10^{10}$ J (b) $9 \times 10^{11}$ J
    (c) $9 \times 10^{12}$ J (d) $9 \times 10^{13}$ J
46. N atoms of a radioactive element emit n alpha-particles per second. The half-life of the element in seconds is
    (a) n/N (b) N/n
    (c) 0.693 N/n (d)0.693 n/N

## ANSWERS

1a ,2c ,3c ,4a ,5b ,6d ,7c ,8c ,9a ,10c ,11c ,12c ,13a ,14c ,15b ,16a ,17b ,18c ,19d ,20c ,21a ,22b ,23b ,24a ,25b ,26d ,27c ,28c ,29b ,30b ,31d ,32b ,33c ,34c ,35d ,36d ,37a ,38d ,39c ,40c ,41c ,42c ,43a ,44a ,45d ,46c





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