Physics Highlights

ELECTROMAGNETIC INDUCTION

- Electromagnetic induction is the phenomenon in which an electromotive force (emf) is induced in a coil of wire with the aid of a magnetic field, resulting in an induced current.

- Faraday realised that an emf and a current can be induced in a loop by changing the amount of magnetic field lines passing through the loop. Consequently, **Faraday's law of induction** states that:

The magnitude of the emf induced in a conducting loop is equal to the rate at which the magnetic flux through that loop changes with time. The induced emf tends to oppose the flux change, and the minus sign indicates that opposition:

$$\text{emf} = -\frac{\Delta\Phi(\vec{B})}{\Delta t}$$

- This opposition is consistent with the Principle of conservation of energy and occurs because

the direction of the current induced in a loop is such that the magnetic field $\vec{B}'$ due to that current opposes the change in the magnetic field $\vec{B}$ inducing the current itself,

as per **Lenz's law**.

- In any conductor a self-induced emf appears whenever the current changes with time. The magnitude of the current has no influence on the magnitude of the induced emf, only the rate of change of the current counts. If the constant L, called self-inductance or simply inductance of a coil, is introduced, Faraday's law can be rewritten so that the induced emf is expressed in terms of the change in current rather than the change in flux:

$$\text{emf} = -L\frac{\Delta i}{\Delta t}$$

- The work done to establish a current in an inductor, such as a solenoid, is stored as energy in its magnetic field.

- Important devices operating according to Faraday's law are transformers and generators, which are key in the worldwide supply of electrical energy.

GLOSSARY AND RELEVANT EXPRESSIONS

generator ▶ alternatore
alternating current (ac) ▶ corrente alternata
to supply ▶ fornire
eddy currents ▶ correnti parassite (eddy = mulinello, vortice)
time-varying ▶ che varia nel tempo
core ▶ nucleo
to store (energy) ▶ immagazzinare (energia)

Activities

1 **Complete the following definitions** with the words listed below.

current • generator • oppose • induces • proportional • transformer • current • conductors • changing • flux

- The effect in which a changing .... in one circuit induces an emf in another circuit is called mutual induction.
- A .... is a device that converts mechanical work into electrical energy. In contrast, an electric motor converts electrical energy into mechanical work.
- The effect in which a changing current in one circuit .... an emf in the same circuit is called self-induction. The self-induced emf acts to .... the change that produces it.
- An induced emf is .... to the change in flux and also to the change in current.
- A .... is a device that is used to increase or decrease an AC voltage: when it steps up the voltage it simultaneously steps down the .... and vice-versa.
- Eddy currents flow in closed loops within .... , and are induced by some nearby time-varying magnetic field.
- An induced emf resulting from a .... magnetic flux always opposes the original change in ....

2 **Complete the following passage** about inductors.

An inductor, usually a long .... , is a device that can be used to produce a known .... field in a specified region. Inductance, like capacitance, depends only on the .... of the device and on the core material. Wrapping a coil around a .... core substantially increases the magnetic flux, and therefore the inductance. Because of their self-inductance, coils or solenoids are known as ....

The induction of a current by a changing .... means that energy is being transferred to that current. Inductors, like capacitors, can store that energy, which is .... to the square of the current. The energy density at any point where a magnetic .... exists is proportional to the .... of the magnetic field itself.

3 **Match the first and second parts of the following sentences** in order to form a passage about Faraday's law of induction.

1. An emf is induced in a loop when the number of magnetic field lines
2. The magnetic flux is proportional to the number of
3. The magnitude of the induced emf is the change in flux divided by
4. A flux that is constant in
5. An induced emf drives current around a circuit just as the
6. and the induced electric field is just as real as
7. electric fields produced in either way exert
8. An emf is induced by a changing magnetic field even if
9. The changing magnetic field induces an
10. The field lines of the induced electric field form
11. In contrast, field lines produced by static particles never do so but must start on

a. field lines that pass through a surface.
b. an electric field produced by static charges:
c. the loop through which the flux is changing is not a physical conductor but is an imaginary line.
d. that pass through the loop is changing.
e. positive charges and end on negative charges.
f. the time interval during which the change occurs.
g. closed loops.
h. time creates no emf.
i. electric field at every point of such a loop.
j. emf of a battery does,
k. forces on charged particles.

MAXWELL'S EQUATIONS AND ELECTROMAGNETIC WAVES

■ Maxwell's equations are about the flux and circulation of electric and magnetic fields: they summarise electromagnetism and form its foundations.

1 **Gauss' law for electricity** states that the net electric flux through a Gaussian surface is proportional to the net electric charge enclosed by the surface, expressing the fact that electric field lines produced by static particles start on positive charges and end on negative charges.

2 **Gauss' law for magnetic fields** says that the net magnetic flux through a Gaussian surface is zero, implying that there can be no individual magnetic poles enclosed by the surface.

3 **Faraday's law** describes the emf induced in a conducting loop by a changing magnetic flux. However, the emf is induced even if the loop through which the flux is changing is not a physical conductor but an imaginary line. The most general form of Faraday's law is thus:

$$\Gamma(\vec{E}) = -\frac{d\Phi(\vec{B})}{dt}$$

4 Ampère's law describes the relationship between the circulation of a magnetic field and the current encircled by the loop, but symmetry considerations suggest that it may also depend on a changing electric flux, as expressed by Maxwell's law of induction: $\Gamma(\vec{B}) = \mu_0\, \varepsilon_0\, d\Phi(\vec{E})/dt$. The two terms are combined together in the so-called **Ampère-Maxwell law**:

$$\Gamma(\vec{B}) = \mu_0\, i + \mu_0\, \varepsilon_0 \frac{d\Phi(\vec{E})}{dt}$$

■ An electric field and a magnetic field oscillating together can form a propagating electromagnetic wave. The various possible frequencies of electromagnetic waves form a spectrum, a small part of which is visible light. An electromagnetic wave is a transverse wave. It can propagate in a vacuum and can be polarised.

GLOSSARY AND RELEVANT EXPRESSIONS

electromagnetic spectrum ▶ spettro elettromagnetico
current encircled by a loop ▶ corrente che attraversa la superficie delimitata da un circuito
X-rays ▶ raggi X

Activities

1 **Complete the following definitions** with the words listed below.

electric • wavelengths • vacuum • oscillating • occur • induced • induces • spectrum

- A magnetic field is .... along a closed loop by the changing electric flux in the region encircled by that loop.
- An .... field is induced along a closed loop by the changing magnetic flux in the region encircled by that loop.
- In electromagnetic waves , the .... electric field induces the magnetic field and the oscillating magnetic field .... the electric field.
- A wave is linearly polarised when its vibrations always .... along one direction, called the direction of polarisation.
- The ordered series of electromagnetic wave frequencies or .... is called the electromagnetic spectrum.
- The portion of the electromagnetic .... to which the eye is sensitive is called visible light.
- The speed of any electromagnetic wave in a .... is *c*.

2 State whether the following sentences are **true or false**. Where false, **rewrite them correctly**.

- Energy is transported to us via a class of waves known as electromagnetic waves.
- As an electromagnetic wave moves through space, it carries energy from one region to another. This energy transport is characterised by the amplitude of the wave.
- Electromagnetic waves can travel through a vacuum or a material substance, since electric and magnetic fields can exist in either one.
- The electric and magnetic fields in an electromagnetic wave are always parallel to each other and to the direction in which the wave is travelling.
- The fields always vary proportionally, with the same frequency and in phase with each other.
- Electromagnetic waves exist with an enormous range of speeds, from values less than 10^4Hz to greater than 10^{24}Hz.
- Electromagnetic waves are longitudinal waves and because of this characteristic they can be polarised.

3 **Match the first and second parts of the following sentences** in order to form a passage about the production of electromagnetic waves.

1. Any electric charge that is accelerating emits
2. The frequency of an electromagnetic wave is determined by
3. Some electromagnetic waves, including x-rays, gamma rays and visible light, are emitted from
4. In an alternating current, an electron oscillates in
5. An antenna consists essentially of
6. A sinusoidally varying current in an oscillator makes charges oscillate sinusoidally along the rods of
7. The electric and magnetic fields produced by this current vary

a. an electromagnetic wave, whether the charge is inside a wire or not.
b. oscillating sources that are of atomic or nuclear size.
c. sinusoidally as well.
d. the oscillation frequency of the electric charges at the source of the wave.
e. two thin, solid, conducting rods.
f. simple harmonic motion along the length of the wire and is one example of an accelerating charge.
g. the antenna, creating an alternating current.

SPECIAL RELATIVITY

■ Special Relativity describes events that are separated in space and in time, and how the results of measurements of these events transform when inertial reference frames move relative to each other. Special Relativity is based upon two postulates.

1 **The relativity postulate**: The laws of physics are the same for all observers in all inertial reference frames, and no frame is preferred over any other.

2 **The speed of light postulate**: The speed of light in a vacuum has the same value c in all directions and all inertial reference frames.

■ According to these postulates, relative motion can change the rate at which time passes, consequently affecting all other time-related physical quantities. More precisely:

simultaneity is not an absolute concept but rather a relative one, depending on the motion of the observers.

■ Besides, if observers moving relative to one another measure the time interval (or temporal separation) between two events, they generally will find different results, an effect known as **time dilation**.

■ Length is a relative quantity as well; in fact the relative motion of observers causes a **length contraction**.

■ The transformations in the space-time coordinates of a single event as seen by observers in two inertial frames are described by the **Lorentz transformations**.

■ Momentum must be redefined, so that the law of conservation of momentum remains valid in all inertial reference frames, as required by the first postulate.

■ Finally, the concept of energy is extended in order to include the energy that Special Relativity associates with the mass of any object – the so-called rest energy.

GLOSSARY AND RELEVANT EXPRESSIONS

with respect to, relative to ▶ relativamente a
time dilation ▶ dilatazione dei tempi
length contraction ▶ contrazione delle lunghezze
rest energy or mass energy ▶ energia a riposo
space-time coordinates ▶ coordinate spaziotmeporali
proper time ▶ tempo proprio
proper length or rest length ▶ lunghezza propria

Activities

1 **Complete the following definitions** with the words listed below.

proper • rest • parallel • smaller • observers • space-time • time • greater

- Three spatial coordinates and one .... coordinate can be assigned to every event: these coordinates are defined collectively as .... coordinates.
- The .... time interval is the interval between two events as measured by an observer who is at rest with respect to the events and who views them as occurring at the same place. All other moving inertial .... will measure a larger value for this time interval.
- The amount by which a measured time interval is .... than the corresponding proper time interval is called time dilation.
- The length of an object measured in the rest frame of the object is its proper length or rest length. Measurements of the length from any reference frame that is in relative motion .... to that length are always .... than the proper length, the difference being the length contraction.
- The energy that is associated with the mass of an object is called mass energy or rest energy, energy that the object has even when it is at ....

2 **Match the first and second parts of the following sentences.**

1. Rotating and otherwise accelerating reference frames are not
2. Length contraction occurs only along the direction of
3. For speeds much less then c, relativistically defined quantities reduce to
4. A consequence of Special Relativity is that objects with mass cannot reach
5. The Lorentz transformations are used to compare
6. In the Galilean transformation equations, time is assumed to pass at
7. When the speed becomes comparable to c, the relativistic momentum becomes

a. the speed c, which represents the ultimate speed.
b. the corresponding classical definitions.
c. the same rate for observers in any reference frame.
d. the velocities that two observers in different inertial reference frames would measure for the same moving particle.
e. inertial reference frames.
f. relative motion, as a direct consequence of time dilation.
g. significantly greater than the non-relativistic momentum.

3 **Fill in the gaps** with the words and expressions listed below.

carried out • length • does not depend • relationships • events • absolute • values • at rest • slowly • equivalent

- Due to postulate 1, there is no experiment that can distinguish between an inertial frame that is .... and one that is moving at constant velocity. Thus, no particular inertial reference frame can be considered as being at .... rest.
- Michelson and Morley .... a series of famous experiments, indicating that the speed of light is the same in all inertial reference frames and .... on the motion of the observer.
- The measured .... of physical quantities are not the same for all inertial observers: it is the .... between physical quantities, as described by physical laws, which remain the same.
- When two observers are moving relative to each other at a constant velocity, each measures the other person's clock as running more .... than his own, and each measures the other person's .... , along the direction of that person's motion, to be contracted.
- Mass and energy are .... , in the sense that a gain or loss of mass can be regarded equally as a gain or loss of energy.
- If two observers are in relative motion, they generally will not agree as to whether two .... are simultaneous, but they will both be correct.

QUANTISATION OF ENERGY

- The mechanism of light emission and absorption can be studied using a model called the **blackbody radiator**, but the electromagnetic wave theory does not match the experimental data.

- Planck assumed that a blackbody is constituted by a large number of atomic oscillators, each of which can absorb and emit only discrete values of energy via electromagnetic waves, the exchanged energy being proportional to the frequency of the electromagnetic waves:

$$E = hf$$

In so doing, Planck introduced the idea of quantisation, which proved to be key in understanding a number of phenomena, such as atomic spectra, the photoelectric effect and the Compton effect.

- Einstein showed that if light is regarded as a collection of quanta (photons), the **photoelectric effect** can be explained: energy is exchanged between a metal and the incident light only if the energy carried by any single photon is greater than the energy required to extract a single electron from its atom (the work function) – that is, if the photon's frequency exceeds the metal's cutoff frequency. As a consequence, above this frequency threshold the photocurrent is directly proportional to the intensity of the incident radiation. If, on the other hand, the light's frequency is not high enough, no effect occurs, even if the intensity (or amount) of the incident light is huge.

- A photon has no mass, nevertheless it not only carries energy but also possesses momentum. The scattering of light by matter, or **Compton effect**, can be explained by applying the laws of conservation to the incident photon and the target electron, as in a classical collision.

- Bohr applied the quantisation of angular moment to the electrons in Rutherford's planetary model of the atom; assuming that these electrons do not radiate electromagnetic waves and that a photon is emitted only when the electron changes orbit. Bohr's model for the hydrogen atom successfully described the observed atomic spectra.

GLOSSARY AND RELEVANT EXPRESSIONS

photon ▶ fotone
threshold ▶ soglia
scattering ▶ diffusione
target ▶ bersaglio
cutoff frequency ▶ frequenza minima
work function ▶ lavoro di estrazione

Activities

1 **Complete the following definitions** with the words listed below.

target • emitted • work • conservation • integer • level • Planck's • depends • electron • photon

- A perfect blackbody absorbs and reemits all the electromagnetic radiation that falls on it, and its emitted radiation .... only on its temperature.
- Quantised quantities are found only as .... multiples of a certain minimum amount, called a quantum.
- The energy of a single .... is the smallest amount of energy that a light wave of a given frequency can have, and it is obtained by multiplying the light's frequency by .... constant.
- In the photoelectric effect electrons are .... from a metal when light shines on it.
- The work function of a metal is the minimum work that must be done to eject an .... from the metal.
- A metal's cutoff frequency is given by the metal's .... function divided by Planck's constant.
- In Compton scattering, X-rays photons scatter as particles, losing energy and momentum to the .... electrons, according to the principles of .... of energy and momentum.
- The spectral lines for hydrogen are grouped in series, according to the .... at which upward jumps start and downward jumps end.

2 **Choose the correct option** in the following sentences about the photoelectric effect.

- When light of high / low enough frequency illuminates a metal surface, electrons can gain / lose enough energy to escape the metal by absorbing / emitting photons.
- The photoelectric effect occurs / does not occur with light of large wavelength.
- The absorbed / ejected electrons move toward a positive / negative electrode called the collector, forming a current that is registered on the ammeter.
- If a photon has energy / frequency in excess of the work needed to remove an electron, the excess appears as kinetic / electric energy of the removed electron.
- If electrons just escape but have no momentum / kinetic energy, the light's frequency corresponds to the cutoff frequency.

3 **Complete the following sentences** about the Compton effect.

The X-ray photon scatters in one direction after the .... , and the electron recoils in another direction. The electron may recoil with a .... comparable to that of light.
The scattered photon has a frequency that is .... than the frequency of the incident photon, because the photon loses .... during the collision. The difference between the two .... depends on the angle at which the scattered photon leaves the collision, so that total .... is conserved.

4 **Match the first and second parts of the following sentences** about atomic models.

1. In Thomson's model, the positive charge was
2. Rutherford proposed that the positive charge was
3. Bohr assumed that the magnitude of the angular moment of the electron in its orbit is
4. Each orbit is characterised by
5. An electron can change energy level by

a. absorbing or emitting the corresponding energy difference.
b. restricted to integer multiples of Planck's constant divided by 2π.
c. concentrated in a small region called the nucleus.
d. a well-defined energy value, from the lowest level or ground state, to the higher or excited states.
e. spread throughout the atom, forming a kind of paste in which the electrons were suspended like plums.

QUANTUM MECHANICS

■ At the beginning of the 20th century, light, which was previously considered as an electromagnetic wave, was discovered to exhibit corpuscular characteristics as well (Einstein's interpretation of the photoelectric effect).

■ Soon after, based on the hypothesis of general symmetry of physical laws, de Broglie proposed that the electron in a circular Bohr orbit should be considered as a wave. The de Broglie's standing waves hypothesis provides an explanation for the angular moment postulate in the Bohr model.

■ Actually, all moving matter has a wavelength associated with it, just like a wave does. Both light and matter exhibit a dual nature: the wavelength (a typical wave quantity) and momentum (a typical particle quantity) of the same physical object are related by the **de Broglie equation**:

$$\lambda p = h$$

■ As an interpretation of the wave-like behaviour of matter, Quantum Mechanics postulates that for any physical system consisting of a particle there is an associated wave-function λ: the probability that the particle will be found at a certain point is proportional to the square of the magnitude of the wave at that point. Wave-functions obey the **Schrödinger equation**.

■ As a consequence of the wave-particle duality, there are limits on the accuracy with which the momentum and position of a particle – as well as the energy of a particle and the time interval during which the particle remains in a given energy state – can be specified simultaneously. **Heisenberg's uncertainty principle** states that

the product of Δp and Δx, as well as ΔE and Δt, is always greater than or equal to Planck's constant divided by 4π.

■ For a correct description of a multiple-electron atom, four quantum numbers are required. The arrangement of the electrons in the shells and subshells obeys the **Pauli exclusion principle**:

no two electrons in an atom can have the same set of values for the four quantum numbers.

GLOSSARY AND RELEVANT EXPRESSIONS

classical mechanics ▶ meccanica classica
matter waves ▶ onde materiali
corpuscular ▶ corpuscolare, particellare
duality ▶ dualismo
particle-like, wave-like ▶ corpuscolare, ondulatorio
wave-function ▶ funzione d'onda
uncertainty ▶ indeterminazione
quantum numbers ▶ numeri quantici
unknown ▶ incognita
probability wave ▶ onda di probabilità

Activities

1 **Complete the following definitions** with the words listed below.

particle • wave • probability • observation • electrons • measure • level • square • behaviour

- Quantum Mechanics is the branch of physics that describes the wavelike .... of matter.
- Matter waves can be interpreted as .... waves.
- Any moving particle can be described as a matter ...., carrying energy and momentum.
- The wave-function Ψ is a function that describes the wave that is associated with a ....
- The probability of an outcome is given by the .... of the corresponding wave-function.
- The term «observer effect» refers to changes that the act of .... will make on the system being observed.
- Heisenberg's uncertainty principle states that it is impossible to .... the position and momentum of a particle simultaneously with unlimited precision.
- In a multiple-electron atom, all .... with the same value of n are said to be in the same shell.
- According to the Pauli exclusion principle, there is a maximum number of electrons that can fit into an energy .... or subshell.

2 **Complete the following sentences with the words «wave», «particle»** and related expressions (e.g. wavelength, particle-like, ...).

- The mathematical description of the ....-.......................... duality of light and subatomic .... provided by Quantum Mechanics is quite satisfactory. On the other hand, an adequate mental picture of it is almost impossible to achieve.
- An object may behave like a .... or like a ...., but never both simultaneously.
- A beam of light is a ...., but it transfers energy and momentum at points, so it exhibits a .... behaviour as well.
- The .... behaviour of matter is observable only for .... whose masses are very small, on the order of the mass of an electron or a neutron.
- The equation $\lambda p = h$ can be used to assign a momentum p to a photon of light with .... λ, but also a .... λ to a .... with a momentum of magnitude p.
- The ability to exhibit interference effects is an essential characteristic of ....
- The fringe patterns in electron-interference experiments show that electrons exhibit .... effects.
- The double-slit experiment reveals the .... aspect of electrons; the photoelectric effect shows the .... aspect of light.

3 **Complete the following sentences** with the words listed below.

position • probability • matter • equivalent • average • square • classical • behaviour • unknown • waves • terms

- Schrödinger's equation is an equation in .... of the wave function Ψ. It is the quantum-mechanical .... of Newton's laws and the principle of conservation of energy in .... mechanics.
- While the .... of a particle is the unknown in Newton's law's, in Quantum Mechanics the .... is the wave function Ψ.
- For subatomic particles only the .... behaviour of large numbers of particles is predictable.
- Schrödinger's equation predicts the future .... of the system in the form of probability of events or outcomes.
- A matter wave Ψ is a .... wave in the sense that the probability of finding a particle at a given point is proportional to the .... of the magnitude of Ψ at that point.
- Light .... are described by Maxwell's equations, ... waves are described by Schrödinger's equation.

NUCLEAR PHYSICS

■ An atomic nucleus is made up of protons and neutrons. The electrostatic force of repulsion between protons is balanced by the strong nuclear force of attraction acting between all nucleons. The strong force is several orders of magnitude greater than the electrostatic force, but it is only effective over a very short range of about 10^{-15} meters. Therefore, in order to separate a stable nucleus into its constituent nucleons a certain amount of energy, called binding energy, is required. Such energy will be found as extra mass of the separated nucleons according to Einstein's equation $E = mc^2$. Energy can also be released by the fusion of two light nuclei, according to the same rules. The most stable nuclei are the middle-mass nuclei.

■ When an unstable nucleus decays spontaneously, α-particles, electrons or positrons and photons may be released. In an α-decay and in a β^--decay the original nucleus transmutes into the $Z - 2$ and $Z + 1$ element, respectively.

■ The energy of nuclei, like that of atoms, is quantised. The typical energy scale of nuclear levels is around 6 orders of magnitude greater than that of atomic levels. Consequently, the energy released per unit mass in nuclear processes is about one million times the energy released in chemical processes; and when a nucleus changes from an excited state to a lower-energy state, very energetic γ-photons are emitted (γ-decay).

■ Decays and nuclear reactions obey the **law of conservation of nucleon number**:

the total number of nucleons remains constant during any nuclear disintegration.

■ It is not possible to predict whether a given nucleus will undergo a decay, however the rate at which decays will take place, dN/dt, is always proportional to the number N of radioactive nuclei present. This leads to the exponential **decay law**:

The number N(t) *of radioactive nuclei present at time* t *equals the initial number of radioactive nuclei* N_0 *times the exponential function of* $-\lambda t$, *where* λ *is the decay constant.*

■ Heavy nuclei can undergo spontaneous or induced fission: in such a process, the original nucleus splits into two fragments with Z very similar to one half of the original Z, plus some small fragments that can trigger a chain reaction. Such a process provides the basis for the commercial generation of power, as in nuclear power plants, and exploitation for military purposes.

GLOSSARY AND RELEVANT EXPRESSIONS

nucleus, nuclei ▶ nucleo, nuclei
binding energy ▶ energia di legame
decay ▶ decadimento
to trigger ▶ innescare / attivare
chain reaction ▶ reazione a catena
power plant ▶ centrale elettrica
half-life ▶ tempo di dimezzamento
mass defect ▶ difetto di massa

Activities

1 Complete the following definitions with the words listed below.

change • second • mass • combines • radioactive • nucleons • nucleus • neutrons • number • law • initial • atomic • less

- Nuclei with the same ....number but different .... numbers are isotopes of one another.
- The «binding energy per nucleon» is the ratio of the binding energy of a .... to the number of .... in that nucleus and is a convenient measure of how well the nucleus is held together.
- A transmutation is a process in which one element is converted into another – namely, a .... in the atomic .... *Z* occurs during the process.
- The activity of a radioactive sample is the number of disintegrations occurring per ....
- The proportionality constant in the decay .... is called the decay or disintegration constant.
- The half-life is the time at which the number of radioactive nuclei has been reduced to one-half its .... value.
- The mean life is the time at which the number of .... nuclei has been reduced to $1/e$ of the initial value.
- The splitting of a massive nucleus into two .... massive fragments is known as nuclear fission.
- A chain reaction is a series of nuclear fissions in which some of the .... produced cause further additional fissions.
- Fusion is a process that occurs naturally in stars, in which a pair of nuclei .... to form a single nucleus.

2 Complete the following sentences with the words: nucleus, nucleons, neutron, protons.

- The masses of .... and .... are approximately equal.
- .... and .... are collectively called ....
- The number of .... in a ...., as well as the number of electrons orbiting it, is given by the atomic number *Z*, which characterises the element.
- The total number of .... in a .... is its atomic mass number *A*.
- The .... are clustered together to form an approximately spherical .... , whose radius is approximately proportional to $A^{1/3}$.
- The binding energy of a .... is the amount of energy needed to break it into its constituent ....
- The sum of the individual masses of the separated .... and .... is given by the mass of the .... plus the mass defect Δm.
- The strong force overcomes the repulsive force between .... and binds together .... and .... , ... and .... , ... and ....

3 Choose the correct option in the following sentences.

- In an α-decay, a nucleus / nucleon spontaneously decays by emitting a helium nucleus / nucleon (α particle).
- In a β-decay, a nucleus spontaneously decays by absorbing / emitting an electron (β^- decay) or a proton / positron (β^+ decay).
- The minus sign in the decay law is present because each disintegration decreases / increases the number of nucleons / nuclei present.
- As time passes, the number of parent / daughter nuclei in a radioactive sample decreases and approaches zero.
- Energy can be released both by fission of high-mass / low-mass nuclei and by fusion of high-mass / low-mass nuclei.
- The electron / proton emitted in a β^--decay is created when a neutron / nucleon decays into a proton and an electron.
- A γ-decay causes / does not cause a transmutation of the element.