KARPAGAM ACADEMY OF HIGHER EDUCATION

SEMESTER – II

		L T P C
17PHP203	**NUCLEAR PHYSICS**	**4 - - 4**

Scope: Nuclear physics is one of the fundamental subjects of physics. It is important to know about the physics of nuclei and the different energies involved in the nuclear processes. Nuclear energy is one of the major sources of energy, which, with proper careful usage, can solve the energy crisis to a large extent.

Objectives: This paper is intended to give an insight into the different nuclear processes and the fundamental particles, which are the real building blocks of the universe.

UNIT - I

Nuclear mass and charge: Distribution of nuclear charge - Nuclear mass and binding energy of a nucleus – semi-empirical mass formula – Nature of nuclear force – form of nucleon-nucleon potential – charge independence and charge symmetry of nuclear forces - Bound states of two nucleons-Ground state of Deuterium - Wave mechanics of ground state of Deuterium-Spin states –Pauli's exclusion principle -Tensor force - Exchange force - Low energy Nucleon - Nucleon scattering

UNIT - II

Radioactivity: Alpha decay: Properties of α particles - Velocity and energy of α particles - Gamow's theory of α particles- Geiger - Nuttall law- α ray energies and fine structure of α rays - α disintegration energy-Low range α particles

Beta decay: Properties of β particles - General features of β ray spectrum – Pauli's hypothesis - Fermi's theory of β particles - Forms of interaction and selection rules - Fermi's and Gamow teller transition

Gamma decay: The absorption of γ rays by matter - Interaction of γ rays with matter - Measurement of γ ray energies - Dumont bent crystal spectrometer method-internal conversion – Applications.

UNIT -III

Nuclear models: Liquid drop model - Bhor Wheeler theory of fission - Condition for spontaneous fission - Activation energy-Seaborg's expression - Shell model: Explanation for magic numbers - Prediction of shell model -Prediction of spin and parity - Nuclear statistics - Magnetic moment of nuclei - Schmidt lines-Nuclear isomerism - Collective model: Explanation of Quadrupole moments - Prediction of sign of electric quadrupole moments. Optical model: Nilsson model - Elementary ideas

UNIT - IV

Nuclear reactions: Nuclear fission and fusion - Kinds of reaction and conservation laws - energetics of nuclear reaction – Applications of Nuclear Energy – Nuclear Reactors - Isospin - Reaction cross section-Continuum theory of nuclear reaction - Resonance - Briet Wigner Dispersion formula - Stages of nuclear reaction - Statistical theory of nuclear reaction -

Evaporation probability and cross section – Kinematics of stopping and pickup reaction - Surface reaction

UNIT -V

High energy physics : Types of interaction in nature-typical strengths and time-scales, conservation laws, charge-conjugation, Parity and Time reversal, CPT theorem, GellMann-Nishijima formula, intrinsic parity of pions, resonances, symmetry classification of elementary particles, quark hypothesis, charm, beauty and truth, gluons, quark confinement, asymptotic freedom.

TEXT BOOKS:

1. Pandya. M.L. and R. P. S. Yadav, 2004, Elements of Nuclear Physics, 1st edition Kedar Nath Ram Nath, Meerut.
2. D.C Tayal , 4th edition 2011, Nuclear Physics, Himalaya Publishing House, New Delhi.

REFERENCES:

1. Kenneth S.Karne, , 1st edition, 2008, Introducing Nuclear Physics, John Wiley and Sons, New York.
2. Sharma. D.C 2004, Nuclear Physics, - K. Nath & Co, Meerut.
3. Bernard L. Cohen, , 1st edition, 2011, Concept of Nuclear Physics, Tata Mc Graw Hill, New Delhi.
4. Devanathan V.,2nd edition, 2008, Nuclear Physics, Narosa Book Distributers Pvt. Ltd., New Delhi.
5. Kaplan Irving, 2002, Nuclear Physics, 2nd Edition, Narosa Book Distributers Pvt. Ltd., New Delhi.

KARPAGAM ACADEMY OF HIGHER EDUCATION
(Deemed to be University Established Under Section 3 of UGC Act 1956)
Coimbatore – 641 021.

LECTURE PLAN
DEPARTMENT OF PHYSICS

STAFF NAME: B. JANARTHANAN
SUBJECT NAME: NUCLEAR PHYSICS SUB.CODE:17PHP203
SEMESTER: II CLASS: I M.Sc (PHY)

S.No	Lecture Duration Period	Topics to be Covered	Support Material/Page Nos
		UNIT-I	
1	1	Distribution of nuclear charge, Nuclear mass and binding energy of a nucleus	T1:109-110
2	1	Semi-empirical mass formula, Nature of nuclear forces	T1:133-135
3	1	Form of nucleon-nucleon potential	T1:135-136
4	1	Charge independence and charge symmetry of nuclear forces	T1:168-169
5	1	Bound states of two nucleons	T1:157-158
6	1	Ground state of deuterium	T1:159-160
7	1	Wave mechanics of ground state of deuterium – spin states	T1:160-161
8	1	Pauli's exclusion principle	T1:163
9	1	Tensor forces, Exchange forces	T1:164-165
10	1	Low energy nucleon	T1:212-213
11	1	Nuclear scattering	T1:213-214
12	1	Revision	
	Total No of Hours Planned For Unit 1=12		
		UNIT-II	
1	1	Properties of α-particles – Velocity and energy of α-particles	T1:274-275

2	1	Gamow's theory of α-decay, Geiger-Nuttal law	T1:285-287
3	1	α-ray energies and fine structure of α-rays	T1:288-289
4	1	α-disintegration energy, Low energy α-particles	T1:290, T1:291
5	1	Properties of β-particles- General features of β-ray spectrum	T1:301-303
6	1	Pauli's hypothesis, Fermi's theory of β-particles	T1:304, T1:305-307
7	1	Form of interaction and selection rules	T1:309-310
8	1	Fermi's and Gamow Teller transition	T1:311
9	1	Absorption of γ-rays by matter, Interaction of γ-rays with matter, Measurement of γ-ray energies	T1:320, T1:321-322, T1:328-329
10	1	Dumont Bent crystal spectrometer method	T1:331-332
11	1	Internal conversion – applications	T1:334-335
12	1	Revision	
	Total number of hours planned for Unit-II = 12		
		UNIT-III	
1	1	Liquid drop model, Bohr-Wheeler theory of fission, Condition for spontaneous fission	T2:418-419, T2:419-420
2	1	Activation energy, Seaborg's expression	T2:420-421
3	1	Shell model, Explanation of magic numbers, Prediction of shell model	T2:421-423
4	1	Prediction of spin and parity, Nuclear statistics	T2:423, T2:424
5	1	Magnetic moments of nuclei, Schmidtt lines	T2:424-425, T2:426
6	1	Nuclear isomerism	T2:426
7	1	Collective model, Explanation of quadrapole moments	T2:433-434
8	1	Prediction of sign of electric quadrapole moments	T2:435

9	1	Optical model	T2:435-436
10	1	Nilson model, Elementary ideas	T2:437-438
11	1	Revision	
	Total No of Hours Planned For Unit III = 11		
		UNIT-IV	
1	1	Nuclear fission and fusion	T2:518
2	1	Kinds of nuclear reaction and conservation laws	T2:519-520
3	1	Energetic of nuclear reaction, Applications of nuclear energy	T2:521-522
4	1	Nuclear reactors, Isospin	T2:322-323
5	1	Reaction cross-section, Continum theory of nuclear reaction	T2:404-405
6	1	Resonance, Breit-Wigner dispersion formula	T2:498-499
7	1	Stages of nuclear reaction	T2:415-416
8	1	Statistical theory of nuclear reaction	T2:417-418
9	1	Evaporation probability, Cross-section for evaporation probability	T2:483-484
10	1	Kinematics of stopping and pickup reaction	T2:375-377
11	1	Surface reaction	T2:378
12	1	Revision	
	Total No of Hours Planned For Unit IV = 12		
		UNIT-V	
1	1	Types of interaction in nature, typical strengths and time-scales, conservation laws	T1:545, T1:546-547
2	1	Charge-conjugation, parity and time reversal	T1:548-549
3	1	CPT theorem, Gell-Mann Nishijima formula	T1:550, T1:551
4	1	Intrinsic parity of pions, resonance	T1:554, T1:555

5	1	Symmetry, Classification of elementary particles	T1:525-526
6	1	Quark hypothesis	T1:580-581
7	1	Charm, beauty and truth, gluons	T1:581-852
8	1	Quark confinement	T1:583
9	1	Asymptotic freedom	T1:584
10	1	Revision	
11	1	Previous year ESE question paper discussion	
12	1	Previous year ESE question paper discussion	
13	1	Previous year ESE question paper discussion	
	Total No of Hours Planned for unit V = 13		
Total Planned Hours	**60**		

Textbook

T1 - Pandya M.L. and R.P.S. Yadav, 2004. Elements of nuclear physics, Ist Edition, Kedarnath /Ramnath, Meerut
T2 - Dayal. D.C., 4th Edition, 2011. Nuclear Physics, Himalaya Publishing House, New Delhi

Reference book

R1 - Kenneth. S. Karne, Ist Edition, 2008. Introducing nuclear physics, John Wiley and Sons, New Delhi
R2 - Sharma D.C., 2004, Nuclear Physics, K.Nath & Co, Meerut
R3 - Bernard. L. Cohen, Ist Edition, 1978. Concept of nuclear physics, Tata McGraw Hill, New Delhi

UNIT-I

SYLLABUS

Nuclear mass and charge: Distribution of nuclear charge - Nuclear mass and binding energy of a nucleus – semi-empirical mass formula – Nature of nuclear force – form of nucleon-nucleon potential – charge independence and charge symmetry of nuclear forces - Bound states of two nucleons-Ground state of Deuterium - Wave mechanics of ground state of Deuterium-Spin states – Pauli's exclusion principle -Tensor force - Exchange force - Low energy Nucleon - Nucleon scattering

NUCLEAR CHARGE DISTRIBUTIONS:

The early theorists, without access to computers, had strong reasons to use analytical descriptions of charge distributions and potentials, that enabled series expansions of analytical solutions of the wave functions within and close to the nucleus. A common choice was the homogeneous charge distribution inside a radius $R = R_0A^{1/3}$, where A is the mass number of nucleus. The most important parameter for many properties is the expectation value r^2 which has the value $3R^2/5$ for the homogeneous nucleus. Already this simple distribution gives the correct analytical behavior of the electronic wave functions at $r = 0$ and has been used in many early analyses, These expansions are also useful for a general understanding of the effects involved.

Experimental information:

Experimental information about charge distributions are derived from many sources, including electron scattering. The experimental data indicate that R_0 1.2 fm gives a reasonable approximation for the homogeneous distribution. Clearly, the tail of a real nucleus is less sharp than indicated by the homogeneous distributions. It is often described in terms of a "skin thickness"

t, defined as the distance in which the charge density falls from 90% of its central value to 10%. Experiments indicate that t is about 2.3 fm for most nuclei.

The primary data from electron scattering experiments are expressed in terms of a "Fourier-Bessel expansion". It is possible to use these data directly, using a numerical approach.

Tabulations often give values relating to additional parameterizations, in particular the two and three-parameter Fermi distributions, as well as Gaussian expansions (de Vries, de Jager & de Vries 1987, Fricke, Bernhardt, Heilig, Schaller, Schellenberg, Schera & de Jager 1995), that are discussed in more detail below.

Another source are muonic X-ray energies. These probe somewhat different moments, the "Barrett moments", of the nuclear distribution. Nevertheless, the results are quoted also in terms of r^2 (Engfer, Schneuwly, Vuilleu- mier, Walter & Zehnder 1974).

Optical isotope shifts provide an important source of complementary information, in particular for chains of radioactive isotopes. It is found that the changes in charge radius along an isotope chain are, in general, smaller than indicated by the textbook formula above. The isotope shifts also reveal an "odd-even staggering" of the r^2 values, providing evidence of nuclear shell structure (Aufmuth, Heilig & Steudel 1987*b*, Otten 1989). A spectacular recent application is the precision determination of the "deuteron structure radius" from the hydrogen-deuterim isotope shift of the 1s – 2s two-photon resonance (Huber, Udem, Gross, Reichert, Kourogi, Pachucki, Weitz & Hänsch 1998).

Nuclear mass and binding energy:

A nucleus consists of Z protons and N neutrons. Let the mass of the nucleus be M (Z, N). If a nucleus is assumed to be a simple collection of Z protons and N neutrons, the mass of the nucleus would be just the sum of the masses of these constituent nucleons, i.e. $ZM_p + NM_n$ where M_p is the mass of proton and M_n is that of neutron.

However, a nucleus is not a simple collection of protons and neutrons (nucleons), but they strongly combine with each other through a strong interaction named the nuclear force.

Mass defect

In general, if two or more particles interact to combine together, then the total mass of the system would decrease to be less than the sum of the masses of the individual particles. The stronger the interaction becomes, the more the mass decreases. This decrease of the mass of the system is called the mass defect. The mass defect of a nucleus of proton number Z and neutron number N is defined by mass defect = $(ZM_p + NM_n) - M(Z,N)$.

Semi-empirical Mass Formula:

$$E_b(MeV) = a_V A - a_S A^{\frac{2}{3}} - a_C \frac{Z^2}{A^{\frac{1}{3}}} - a_A \frac{(A-2Z)^2}{A} \pm \delta(A,Z)$$

$$\delta(A,Z) = \begin{matrix} +\delta_0 \; for \; Z, N \; even \\ 0 \\ -\delta_0 \; for \; Z, N \; odd \end{matrix}$$

This formula is called the Weizsaecker Formula (or the semi-empirical mass formula). The physical meaning of this equation can be discussed term by term.

Volume term :– $a_V.A$. The first two terms describe a spherical liquid drop of an incompressible fluid with a contribution from the volume scaling with A and from the surface, scaling with $A^{2/3}$. The first positive term $a_V.A$ is known as the volume term and it is caused by the attracting strong forces between the nucleons. The strong force has a very limited range and a given nucleon may only interact with its direct neighbors. Therefore this term is proportional to A, instead of A2. The coefficient a_V is usually about ~ 16 MeV.

Surface term – $a_{sf}.A^{2/3}$. The surface term is also based on the strong force, it is, in fact, a correction to the volume term. The point is that particles at the surface of the nucleus are not completely surrounded by other particles. In the volume term, it is suggested that each nucleon interacts with a constant number of nucleons, independent of A. This assumption is very nearly true for nucleons deep within the nucleus, but causes an overestimation of the binding energy on the surface. By analogy with a liquid drop this effect is indicated as the surface tension effect. If the volume of the nucleus is proportional to A, then the geometrical radius should be proportional to $A^{1/3}$ and therefore the surface term must be proportional to the surface area i.e. proportional to $A^{2/3}$.

Coulomb term – $a_C.Z^2.A^{-1/3}$. This term describes the Coulomb repulsion between the uniformly distributed protons and is proportional to the number of proton pairs Z^2/R, whereby R is proportional to $A^{1/3}$. This effect lowers the binding energy because of the repulsion between charges of equal sign.

Asymmetry term – $a_A.(A-2Z)^2/A$. This term cannot be described as 'classically' as the first three. This effect is not based on any of the fundamental forces, this effect is based only on the Pauli exclusion principle (no two fermions can occupy exactly the same quantum state in an atom). The heavier nuclei contain more neutrons than protons. These extra neutrons are necessary for stability of the heavier nuclei. They provide (via the attractive forces between the neutrons and protons) some compensation for the repulsion between the protons. On the other hand, if there are significantly more neutrons than protons in a nucleus, some of the neutrons will be higher in energy level in the nucleus. This is the basis for a correction factor, the so-called symmetry term.

Pairing term – $\delta(A,Z)$. The last term is the pairing term $\delta(A,Z)$. This term captures the effect of spin-coupling. Nuclei with an even number of protons and an even number of neutrons are (due to Pauli exclusion principle) very stable thanks to the occurrence of 'paired spin'. On the other hand, nuclei with an odd number of protons and neutrons are mostly unstable.

Nature of nuclear force:

The strong forces of attraction which firmly hold the nucleons in the nucleus are known as nuclear forces. The forces holding the nucleus together must be extremely strong. This is clear from the fact that the positively charged protons remain confined to the small volume of the nucleus. If the nuclear forces are weak, the electrostatic repulsion of the positively charged protons would tend to break the nucleus apart or at the very least, the nucleus would occupy a much larger volume. These forces exist between the nucleons i.e. between a neutron and a proton, between two protons and between two neutrons. The stability of the nucleus is accounted for due to the presence of these forces.

Some important properties of nuclear forces are

- They are attractive in character
- They exert attractive forces on the nucleons. Hence they are also called cohesive forces.
- They are charge independent
- They are the same between p and n or between p and p or between n and n. These forces do not depend upon the charge on the nucleons.
- They are short range forces
- It has been found that they are quite strong for an inter nucleon distance of the order of 10-15 m but become zero at an inter nucleon distance of 10 -14 m. Nuclear forces change with distance between the nucleons.
- They have saturation character

- They abruptly become zero as the inter-nucleon distance is increased to a certain value. Therefore, nuclear forces do not increase with the increase in the number of nucleons.
- They are extremely strong :
- Their magnitude is so high that a huge energy is required to divide a nucleus into its constituents. The relative strengths of gravitational (FG), electrostatic (Fe) and nuclear (FB) forces acting in the nucleus is given below, FG : Fe : FB = 1 : 1036 : 1038
- The nuclear forces are dependent on the spin of the nuclei.
- Nuclear forces are non-central forces
- The force between two nucleons does not act along the line joining their centers. This shows that nucleons in the nucleus are not spherically symmetric.

Form of Nucleon-Nucleon potential:

Let us discuss in some more detail the interaction between nucleons. In the past there has been a tremendous experimental effort devoted to scattering protons on protons and neutrons on protons. Since the neutron target is not available, the neutron-neutron scattering was inferred mostly from the scattering of protons on deuterons. All this effort led to a large database of cross-sections and phase shifts that provide the most extensive information on the binary interactions on nucleons. There have also been numerous attempts to model the interaction between nucleons by different kinds of potentials.

The electromagnetic part contains not only the standard Coulomb interaction between protons, but also various other terms like the two-photon Coulomb terms, vacuum polarization terms, and magnetic-moment interactions.

Charge independence and charge symmetry:

The neutron and the proton are regarded as two different states of the same entity, called the nucleon, differing only in their electrical charge. These are strong evidences to show that the basic force between two neutrons, as also between two protons, within the nuclei, is the same. This of course does not take into account the electrostatic repulsion between the protons. Symbolically, we can express this fact by writing

$$(n\text{-}n) = (p\text{-}p)$$

This is known as the charge symmetry of the nuclear force.

In addition the force between the neutron and the proton in s state is also equal to the above two forces, a fact known as the charge independence of the nuclear force.

(n-n) = (p-p) =(p-n)

Thus there is a basic symmetry of the nuclear forces which is broken only by the electromagnetic interaction due to the charge on the proton.

Ground state of deuterium: (Wave mechanics of ground state of deuterium)

The gravitational potential energy for the Deuteron nucleus is found to be

$$V(r) = -\frac{g^2 \hbar c}{M_0^2} \frac{m_p m_n}{r}, \qquad (1.1)$$

where,

$$g^2 = \frac{e^2}{0.2254} = 0.032384. \qquad (1.2)$$

In the above expression $e^2 = \frac{1}{137}$ is the fine structure constant and 0.2254 is the Weinberg mixing parameter. The parameter M_0^2 is different for each nucleus. For the Deuteron nucleus it is given by,

$$M_0^2 = 0.931826 \times 10^{-48} \text{ gm}^2. \qquad (1.3)$$

The time independent Schrödinger equation for the deuteron is given by,

$$\left[-\frac{\hbar^2}{2\mu}\nabla^2 + V(r)\right]\Psi(r,\vartheta,\phi) = E\Psi(r,\vartheta,\phi). \qquad (1.4)$$

Here the reduced mass μ is given by,

$$\mu = \frac{m_p m_n}{m_p + m_n} = 0.836883 \times 10^{-24} \text{ gm}. \qquad (1.5)$$

The spherically symmetric potential leads to the solution

$$\Psi(r,\vartheta,\phi)=R_{n\ell}(r)Y_{\ell m}(\vartheta,\phi), \tag{1.6}$$

Where the quantum numbers n, ℓ and m have the following values as in the case of the hydrogen atom:

$$n=1,2,3\cdots \text{ and } \ell=0,1,2,\cdots,n-1,$$
$$\text{and } m=-\ell,-\ell+1,,\cdots,+\ell$$

The radial wave function is given by,

$$R_{n\ell}=A\mathrm{e}^{-\frac{\rho}{2}}\rho^{\ell}L_{n+\ell}^{2\ell+1}(\rho). \tag{1.7}$$

The dimensionless parameter ρ in Equation (1.7) is given by,

$$\rho=\frac{2r}{na_0} \text{, where n is the principal quantum number.} \tag{1.8}$$

Here,

$$a_0=\frac{\hbar^2}{\mu}\frac{M_0^2}{g^2\hbar c m_p m_n}=4.31734\times10^{-13}\text{ cm}. \tag{1.9}$$

The energy spectrum for this case is given by,

$$E_{n\ell}=-\frac{\mu}{2\hbar^2}\frac{1}{n^2}\left(\frac{g^2\hbar c m_p m_n}{M_0^2}\right)^2=-\frac{2.2251}{n^2}\text{ MeV}. \tag{1.10}$$

The normalization constant A in Equation (1.7) is given by,

$$A=\sqrt{\left(\frac{2}{na_0}\right)^3\frac{1}{2n}\frac{(n-\ell-1)!}{\left[(n+\ell)!\right]^3}}. \tag{1.11}$$

All the above results are obtained by a simple transcription of the hydrogen atom results with an appropriate change of variable. The ground state energy of the deuteron nucleus is given by −2.2251 Mev. This is an excellent result. The radius of the deuteron nucleus is half of Equation (1.9) whereas Equation (1.9) gives the distance between the two nucleons. The radius is the distance of either of the nucleons from the center of mass. This result also agrees pretty well with the experiment. There are excited energy levels but these are a blessing in disguise. These will be necessary to explain the quadrupole moment of the deuteron nucleus as we show in the next section.

Paulis exclusion principle

The Pauli Exclusion Principle states that, in an atom or molecule, no two electrons can have the same four electronic quantum numbers. As an orbital can contain a maximum of only two electrons, the two electrons must have opposing spins. This means if one is assigned an up-spin (+1/2), the other must be down-spin (-1/2).

Electrons in the same orbital have the same first three quantum numbers, e.g., n=1n=1, l=0l=0, ml=0ml=0 for the 1s sub shell. Only two electrons can have these numbers, so that their spin moments must be either ms=−1/2ms=−1/2 or ms=+1/2ms=+1/2. If the 1s orbital contains only one electron, we have one ms value and the electron configuration is written as 1s1 (corresponding to hydrogen). If it is fully occupied, we have two ms values, and the electron configuration is 1s2 (corresponding to helium).

The 1s and 2s sub shells for beryllium atoms can hold only two electrons and when filled, the electrons must have opposite spins. Otherwise they will have the same four quantum numbers, in violation of the Pauli Exclusion Principle.

Nuclear Magnetic Moments

Associated with each nuclear spin is a magnetic moment which is associated with the angular momentum of the nucleus. It is common practice to express these magnetic moments in terms of the nuclear spin in a manner parallel to the treatment of the magnetic moments of electron spin and electron orbital angular momentum.

For the electron spin and orbital cases, the magnetic moments are expressed in terms of a unit called a Bohr magneton which arises naturally in the treatment of quantized angular momentum

Exchange force:

Modern field theory is based on a model in which fundamental forces are transmitted by the exchange of bosons (integer spin). The most obvious example is the electromagnetic interaction which is transmitted by photons. Most nuclear processes however can be understood in terms of what we have referred to as the 'left over' nuclear force. There is no need to deal directly with the fundamental strong force between quarks. Nevertheless in working with the nuclear force it is still possible to use the concept of exchange and in fact one of the earliest applications of such a concept was made in this area. At low energies, only the outer part of the force field which surrounds the nucleon is involved and this is dominated by single pion exchange. The pion is the lightest meson, it has zero intrinsic spin and belongs to an isospin triplet t = 1 with t3 = +1 (pi-plus), 0 (pi-zero), -1 (pi-minus). As stated above the electromagnetic interaction is transmitted by the photon and this has zero rest mass. In the case where the exchanged boson has non-zero rest mass we can examine what effect this has on the shape of the field around a source, by drawing a parallel with electrostatics. For a field transmitted by a particle with mass we start with the relativistic expression relating energy and momentum in this case $E_2 = p_2c_2+m_2c_4$

This is called the Yukawa potential since the original proposal that nuclear binding forces were due to particle exchange was made by the Hideki Yukawa in 1935, and from knowledge of the range of the force he was able to predict the mass of the particle using the sort of argument we have described above. Cecil Powell discovered the pion in 1947 in cosmic rays. Yukawa was awarded the Nobel prize in 1949 and Powell was awarded it in 1950.

We now examine what might be the result of exchange between two nucleons in terms of their spin and isospin. This is illustrated simply below. The red disks represent protons and the blue disks are neutrons with spin states indicated by the attached arrows.

The effect of the exchange of a quantity between two particles can be represented by an operator P which operates on the wave function describing the two particle state. In this case the effective potential is written V(r)P where V(r) is a normal attractive central potential. Although such a potential has little meaning in classical mechanics it causes no difficulty in quantum mechanics since it is just incorporated into the Schrödinger equation.

We will look at the effect of P in each case illustrated above to get some idea of the different components of the nuclear potential. This is clearly much more complicated than the Coulomb potential of an atom. If we include the tensor force then we have a simple physical argument for considering a two nucleon interaction made up of at least six component potentials. This is not all since we should also include velocity dependent forces which are important in scattering processes but which also show effects in nuclei - for example the spin-orbit force.

Finally, as we have mentioned above, the nuclear force has a repulsive core which prevents the nuclei from collapsing in on themselves. We conclude this section with a crude sketch of the nucleon-nucleon potential illustrating some of the types of particle exchange which are thought to contribute.

Tensor force:

Deuteron spends about 96% of its time in an l=0; 1s state and the remaining 4% of its time in an l=2 , 1d state. For both l=0 and l=2 we have s=1.

Thus one can account for the observed dipole and qudrapole moments of the deuteron by considering an admixture of l=2 value in to l=0 value in the corresponding wave function what is the physical effect of changing the angular momentum of the system from l=0 to l=2. Obviously a torque must be considered to act. This torque is related to the potential.

We thus see that a change in the angular momentum implies that the potential v is not. Just a function of r as assumed previously, but is function of angle also. the force responsible for this is dependent not on r alone as in the case of a pure central force. It also depends on angle, the angle between the spin angular momentum direction and the line joining the nucleons. This force is clearly a non-central force and it is called the tensor force.

The value of the tensor force depends on the angle which is measured from the direction of the spin vector S. therefore the tensor force is a function of s.r. the tensor force is similar to the force law for two magnets, which depend on the way they are oriented.

Neutron-Proton scattering

Consider low energy neutron proton scattering. The deuteron, the bound state of neutron and proton tellsus something about the interaction. The deuteron is the only bound state of neutron and proton. It has $J = 1$, binding energy of 2.23MeV. It has a quadrupole moment. As there is no $J = 0$ bound state, the interaction depends on spin. The most general state with spin 1 is

$$\Psi = a|\,{}^3S_1\rangle + b|\,{}^3P_1\rangle + c|\,{}^1P_1\rangle + d|\,{}^3D_1\rangle.$$

The magnetic moment of the deuteron is roughly $\mu_n + \mu_p$. The contribution from $l = 1$ would be much larger so there can not be much $l = 1$ in the wave function. If the interaction is parity invariant then either $b = c = 0$ or $a = d = 0$. Must be that $b = c = 0$ in view of the small magnetic moment and $|D| \ll |a|$. Since there is a quadrupole moment, and we know that $l = 0$ is speherically symmetric, it must be that $|d| \neq 0$. The expectation value of the quadrupole meomtn will be

$$\langle Q\rangle = d\,\langle{}^3S_1 \mid Q \mid {}^3D_1\rangle + c.c. + O(d^2).$$

As there are both $l = 0$ and $l = 2$ contributions to the wave functions, the interatino does not conserve orbital angular moemntum, only total.

Write an interaction potential that distinguishes $l = 0$.

$$V = V_s(r)P_s + V_t(r)P_t,$$

where P_s and P_s are the singlet and triplet projection operators.

$$P_s = \frac{1}{4}(1 - \sigma_{\mathbf{n}} \cdot \sigma_{\mathbf{p}}), \qquad P_t = \frac{1}{4}(3 + \sigma_{\mathbf{n}} \cdot \sigma_{\mathbf{p}}) \tag{1}$$

Then

$$M(\mathbf{k}_f, \mathbf{k}_i) = f_s(k,\theta)P_s + f_t(k,\theta)P_t \tag{2}$$

For the unpolarizedbeam, the initial spin density matrix is $\phi_i = \frac{1}{4}$. The differentiual cross section is

$$\frac{d\sigma}{d\Omega} = \frac{1}{4}\mathrm{Tr}(P_s|f_s|^2 + P_t|f_t|^2) \tag{3}$$

$$= \frac{1}{4}(|f_s|^2 + 3P_t|f_t|^2) \tag{4}$$

After scattering the most general spin-density matrix is

$$\rho = \frac{1}{4}\left(1 + \sigma_{\mathbf{n}} \cdot \mathbf{P_n} + \sigma_{\mathbf{p}} \cdot \mathbf{P_p} + \sum_{i,j=1}^{3} \sigma_{n,i}\sigma_{p,j}C_{ij}\right) \tag{5}$$

We find if the initial spin state is random

$$\rho_f = \frac{1}{4}\frac{|f_s|^2P_s + |f_t|^2P_t}{d\sigma/d\Omega} = \frac{d\sigma/d\Omega + \frac{1}{4}\sigma_{\mathbf{n}} \cdot \sigma_{\mathbf{p}}(|f_t|^2 - |f_s|^2)}{4(d\sigma/d\Omega)} \tag{6}$$

and

$$C_{ij} = \delta_{ij}\frac{|f_t|^2 - |f_s|^2}{4(d\sigma/d\Omega)}$$

Low energy Scattering

Consider s-wave scattering from a square well potential with $V = V_0$ for $r < R$ and zero otherwise. The general solution for a free particle (outside the potential) for each partial wave

$$A_l(r) = e^{i\delta_l}[\cos\delta_l j_l(kr) - \sin\delta_l n_l(kr)] \tag{7}$$

and for s-wave

$$A_0(r) = e^{i\delta_0}[\cos\delta_0 j_0(kr) - \sin\delta_0 n_0(kr)] = e^{i\delta_0}\sin(kr + \delta_0) \tag{8}$$

At $r < R$, with the requirement that $u(0) = 0$, solutions to the Schrodinger equation

$$-\frac{\hbar^2}{2m}\frac{d^2u}{dr^2} + V_0 = E \tag{9}$$

are $u(r) = A\sin k'r$ with $k' = \sqrt{2m(E - V_0)}/\hbar$. Then match logarithmic derivative at the boundary $r = R$.

$$\begin{aligned} k'\cot k'R &= k\cot(kR + \delta_0) & (10)\\ \rightarrow k'\tan(kR + \delta_0) &= k\tan k'R & (11)\\ \rightarrow \delta_0 &= \tan^{-1}\left(\frac{k}{k'}\tan(k'R)\right) - kR & (12) \end{aligned}$$

Since the scattering amplitude for $l = 0$ is

$$f(\theta) = \frac{1}{2ik}e^{i\delta_0}\sin\delta_0 \tag{13}$$

the differential cross section becomes

$$\frac{d\sigma}{d\Omega} = \frac{1}{4k^2}\sin^2\delta_0$$

If the potential is attractive, $V_0 = -|V_0|$, the cross section will reach a maximum whenever $\delta_0 = (n + \frac{1}{2})\pi$. If the potential is attractive, $V_0 < 0$, and $k' < k$, then as we increase the energy from zero, the cross section will go through resonances as δ_0 goes through $(n + \frac{1}{2})\pi$.

For very low energy, $k \rightarrow 0$, from Equation 12 we get

$$\begin{aligned} \delta_0 + kR &\sim \frac{k}{k'}\tan(k'R)\\ k(-a + R) &\sim \frac{k}{k'}\tan(k'R)\\ \rightarrow a &\sim R - \frac{\tan k'R}{k'} \end{aligned}$$

Then the cross section is independent of energy and

$$\sigma = 4\pi\frac{1}{k^2}\sin\delta_0^2 = 4\pi a^2 \tag{14}$$

If $k'R \sim \pi/2$ then the cross section can be very large at very low energy.

KARPAGAM ACADEMY OF HIGHER EDUCATION,COIMBATORE-21
DEPARTMENT OF PHYSICS
CLASS:I MSC PHYSICS
NUCLEAR PHYSICS (17PHP203)
MULIPLE CHOICE QUESTIONS

QUESTIONS	opt1	opt2	opt3	opt4	answer
Unit - I					
The atomic number is equivalent to which of the following?	The number of neutrons in the atom	The number of protons in the atom	The number of nucleons in the atom	The number of α–particles in the atom	The number of protons in the atom
The atomic mass number is equivalent to which of the following?	The number of neutrons in the atom	The number of protons in the atom	The number of nucleons in the atom	The number of α–particles in the atom	The number of nucleons in the atom
Which of the following particles has the smallest mass?	Proton	Electron	Neutron	Nucleus	Electron
Which of the following statements about the mass of an atom is true?	It is evenly divided between the protons and the orbiting electrons	It is evenly divided between the nucleons and the orbiting e	It is concentrated in the electron cloud	It is concentrated in the nucleus	It is concentrated in the nucleus
Neutrons has the charge	1639 times of an electron	1739 times of an electron	1839 times of an electron	1939 times of an electron	1839 times of an electron
Which of the following is correct for the number of neutrons in the nucleus?	N = A –Z	N = Z – A	N=Z +A	N = Z	N = A –Z
What law did Ernest Rutherford use to estimate the size of the nucleus?	Conservation of nucleon number	Conservation of angular momentum	Conservation of linear momentum	Conservation of energy	Conservation of energy
Why are nuclear energy levels more complex than electron energy levels?	Nuclear energy levels depend only on attractive forces.	Nuclear energy levels depend on attractive and repulsive fo	Nuclear energy levels are an order of one hundred tin	Electron energy levels depend on the interaction between neutrons	Nuclear energy levels depend on attractive and repulsive forces
Which of the following about the nuclear force is true?	It is an attractive force between electrons and protons in an atom	It is an attractive force between electrons and neutrons in a	It is much weaker than the electromagnetic force	It is a strong, short-range, attractive force between the nucleons	It is a strong, short-range, attractive force between the nucleons
Isotopes of an element:	have the same number of protons and electrons, but a different number of neutrons	have the same number of protons and neutrons, but a differ	have different number of protons	have different number of electrons	have the same number of protons and electrons, but a different number of neutrons
Binding energy is:	the amount of energy required to break a nucleus apart into protons and neutrons	the amount of energy required to break a nucleus apart into	the amount of energy required to break a nucleus apa	the amount of energy released when neutrons change energy level	the amount of energy required to break a nucleus apart into protons and neutrons
When nucleons form a stable nucleus, binding energy is:	created from nothing	destroyed into nothing	transformed into visible light	released as high energy photons or particles	released as high energy photons or particles
An isotope with a high Binding Energy per nucleon:	will decay in a short period of time	is very unstable	is very stable	has very few electrons	is very stable
Why do heavier nuclei have a greater ratio of neutrons to protons than lighter nuclei?	to add more nucleons so that the binding energy is greater	to provide a greater weak nuclear force	to provide more attractive electromagnetic force	to provide more attractive strong nuclear force to balance the repu	to provide more attractive strong nuclear force to balance the repulsive electromagnetic force
The fact that the binding energy per nucleon is roughly a constant over most of the range of stable nuclei is a consequence of the fact that the nuclear force is	short range	long range	weak	strong	short range
Nucleus "a" contains 5 protons and 5 neutrons and has radius R. The radius of nucleus "b", which contains 35 protons and 45 neutrons, is closest to:	8R	R	2R	1.4R	2R
The particles which can be added to the nucleus of an atom without changing its chemical properties are called	Electrons	Neutrons	Protons	None of the above	Neutrons
The mass number of a nucleus is	Always less than its atomic number	Always equal to its atomic number	Always more than its atomic number	Sometimes more than & sometimes equal to its atomic number	Sometimes more than & sometimes equal to its atomic number
Barlett forces is	The exchange of the spin coordinates	The exchange of the space coordinates	An exchange of both the position and the spin coordi	None of the above	The exchange of the spin coordinates
Forces involved in proton-proton scattering is	Nuclear forces	Coulomb repulsive forces	Nuclear as well as coulomb repulsive forces	Electromagnetic forces	Nuclear as well as coulomb repulsive forces
Which one of the following hypothesis supports the charge independence of nuclear forces?	The nuclear forces between n-p, n-n and p-p are equal	The nuclear forces between n-n and p-p are equal	The nuclear forces between n-p and p-p are not equal	None of the above	The nuclear forces between n-p, n-n and p-p are equal
Which of the following is in the increasing order for the stability of nucleus	e-e, e-o, o-o nuclei	e-o, e-e, o-o nuclei	o-o, e-o, e-e nuclei	None of the above	o-o, e-o, e-e nuclei
The energy equivalent of 1 a.m.u. is	933.17MeV	93.3 MeV	9331MeV	None of these	933.17MeV
Nucleus contains protons and neutrons. The electrons revolve around the nucleus. For atoms of small mass, the relation between proton p, neutron n and electron e is	p=n=e	p=e=n	p=e=n	n=p-1=e	p=e=n
Stability of atomic nucleus is not influence by	Mass defect	Binding energy	Neutron-proton ratio	Ionisation potential	Ionisation potential
In stable nuclides up to Z=20, the n/p ratio=	1	>1	<1	None of these	1
The asymmetry terms in the Weizsacker semi-empirical formula is because of	Non-spherical shape of the nucleus	Non-zero spin of nucleus	Unequal number of protons and neutrons inside the n	Odd number of protons inside the nucleus	Unequal number of protons and neutrons inside the nucleus
The size of the nucleus cannot be determined by	Electron scattering	Energy levels of muonic atoms	Excited state energy of the isotopic spin multiplet	By selecting the probe using concept of de-Broglie wavelength	Excited state energy of the isotopic spin multiplet
The relative strength of the gravitational coulomb's and nuclear forces are	Fg :Fe:Fn=1:10^{36}:10^{38}	Fg :Fe:Fn=1:10^38:10^36	Fg :Fe:Fn=1:10^30:10^38	none of these	Fg :Fe:Fn=1:10^36:10^38
Which of the following statements is in correct for the nuclear force between two nucleon	it is charge independent	it is spin dependent	it is velocity dependent	it is independent of non –central component	it is independent of non –central component
Isotopic spin of the nuclear ground state for deuteron	1	0	½	-0.5	0
At the peaks of the nuclear binding energy curve	Z is even but N is odd	Z is odd and N is even	Both Z and N are odd	Both Z and N are even	Both Z and N are even
A deuteron spends	96% time in S state and 4% time in D state	96% time in S state and 4% time in P state	92% time in S state and 8% time in D state	92% time in S state and 8% time in P state	96% time in S state and 4% time in D state
The average energy required to extract one nucleon from the nucleus is called	Bonding energy	Bonding energy per nucleon	Bonding energy of atom	none of these	Bonding energy per nucleon
According to Yukawa theory, the nuclear forces between the nucleons act through the existence of	Positron	µ-meson	K-meson	π-meson	π-meson
A deuteron	Cannot be disintegrated by photons	Can be disintegrated by photon of minimum energy 1.02Me	Can be disintegrated by photon of minimum energy 2	Can be disintegrated by photon of minimum energy 8MeV	Can be disintegrated by photon of minimum energy 2.22MeV
Nuclei with the same mass number A, but different atomic number Z, are called	Isotopes	isobars	isomers	isotones	Isotopes
Isotopes are nuclei with the same atomic number Z but different	Neutron number	Proton number	mass number	none of these	mass number
Nuclei, with an equal number of neutrons are called	isobars	isotones	isomers	Isotopes	isotones
The atoms, which have the same Z and same A but are distinguished by their different life times are called	Isotopes	isotones	isomers	isobars	isomers
Nuclei, having the same mass number A, but with the proton and neutron number interchanged are called	Isobars	isotones	Mirror nuclei	isomers	Mirror nuclei
Dimension of nucleus is of the order of 1 Fermi. With what velocity should electrons move so that it is found inside the nucleus?	7*10^11 m/s	3*10^8 m/s	6*10^8 m/s	1.5*10^{8} m/s	7*10^11 m/s
The charge symmetry of the nuclear force is given by	(n-p)= (n-n) = (p-p)	(n-p) = (p-p)	(n-n) = (p-p)	(n-n) ≠ (p-p)	(n-n) = (p-p)
A tensor force is capable of explaining the deuteron	Quadrupole moment	Dipole moment	Octupole moment	Monopole	Quadrupole moment
Majorana force is	The exchange of the space coordinates	The exchange of the spin coordinates	An exchange of both the position and the spin coordi	None of the above	The exchange of the space coordinates
Heisenberg force is	The exchange of the space coordinates	An exchange of both the position and the spin coordinates	The exchange of the spin coordinates	None of the above	An exchange of both the position and the spin coordinates
Heisenberg's idea of exchange forces are useful in explaining the	Short range nuclear force	Charge independence	Charge symmetry	Saturation of nuclear forces	Saturation of nuclear forces
The coulomb repulsion term which contributes to the binding energy of a nucleus AXZ is proportional to	Z	2Z	Z(Z-1)	It is independent of Z	Z(Z-1)
In the nucleus the forces exist between nucleons, called	Coulomb's force	Nuclear force	Atomic force	Nucleons force	Nuclear force
Nuclear forces are non-central forces and are	Spin independent	Spin dependent	Both (a) and (b)	None of these	Spin dependent
Existence of an electric quadrupole moment in deuteron indicates that non-central type of forces are called	Tensor forces	Nuclear forces	Proton forces	Deuteron forces	Tensor forces
Stability of atomic nucleus is not influence by	Mass defect	Binding energy	Neutron-proton ratio	Ionisation potential	Ionisation potential
Proton has the charge	1637 times of an electron	1737 times of an electron	1837 times of an electron	1937 times of an electron	1837 times of an electron
The nucleus consists of	Neutrons	Protons	neutrons and protons	electrons and neutrons	neutrons and protons
Nucleus is	positively charged	negatively charged	neutral	charge keeps on changing	positively charged
An unknown chemical element is presented by the following formula: $_{Z}X^{A}$. What is the name of index Z?	Atomic mass number	Atomic number	Principle quantum number	Orbital quantum number	Atomic number
An unknown chemical element is presented by the following formula: $_{Z}X^{A}$. What is the name of index A?	Atomic mass number	Atomic number	Principle quantum number	Orbital quantum number	Atomic mass number
How many electrons are in the $_{6}C^{12}$ atom?	12	6	18	3	6
How many nucleons are in the $_{10}Ne^{20}$ atom?	12	30	18	20	20
How many neutrons are in the $_{11}Na^{23}$ atom?	12	11	18	24	12
How many protons are in the $_{7}N^{14}$ atom?	14	6	7	10	7
Low energy nucleon-nucleon scattering involves only	l = 0	l = 1,2,3	l = 0,1,2,3	l = 1, S=1	l = 0
A nucleus with A=235 splits into two new nuclei whose mass numbers are in the ratio 2:1. Then the radii of new nuclei is	5.99fm,7.55fm	6.99fm, 8.55fm	2.3fm,4.55fm	none of these	5.99fm,7.55fm
Rest mass of proton is	1.6725 $\times 10^{-31}$kg	1.6725 $\times 10^{-27}$kg	1.6725 ×10-27g	None of these	1.6725 ×10-27kg
The size of the nucleus cannot be determined by	Electron scattering	Energy levels of muonic atoms	Excited state energy of the isotopic spin multiplet	By selecting the probe using concept of de-Broglie wavelength	Excited state energy of the isotopic spin multiplet
The ratio of the sizes of $_{82}Pb^{208}$ and $_{12}Mg^{26}$ nuclei is approx.	2	4	8	16	2
Calculate the mass defect of 235U. The mass of U-235 is 235.0439 AMU.	1.91392 AMU	0.19132AMU	0	-1.9132AMU	1.91392 AMU

Prepared by Dr. B. Janarthanan, Associate Professor, Department of Physics, KAHE

UNIT-II

SYLLABUS

Radioactivity: Alpha decay: Properties of α particles - Velocity and energy of α particles - Gamow's theory of α particles- Geiger - Nuttall law- α ray energies and fine structure of α rays - α disintegration energy-Low range α particles
Beta decay: Properties of β particles - General features of β ray spectrum – Pauli's hypothesis - Fermi's theory of β particles - Forms of interaction and selection rules - Fermi's and Gamow teller transition
Gamma decay: The absorption of γ rays by matter - Interaction of γ rays with matter - Measurement of γ ray energies - Dumont bent crystal spectrometer method-internal conversion – Applications

Properties of α particles:

1. Alpha, α – particle carries double the positive charge of proton, which is equal to the charge on the helium nucleus.
2. Mass of an alpha, α – particle is roughly four times that of hydrogen atom i.e. it is equal to the mass of the helium nucleus.

The above two properties establish that an alpha, α – particle is equivalent to helium nucleus (or a helium atom which has lost its two orbital electrons i.e. a doubly ionized helium atom).

3. Alpha, α – particles are deflected by electric and magnetic fields.
4. The velocity of alpha, α – particle ranges between 1.4 x 107 ms^{-1} to 2.1 x 107 ms^{-1}, depending upon the source emitting it.
5. Because of large mass, the penetrating power of α – particle is very small, it being 1/100 times that due to beta, β – rays and 1/10,000 times that due to γ – rays . α – particle can be easily stopped by an aluminium sheet, only 0.02 mm thick.
6. Because of large mass and large velocity, α – particle have large ionizing power. Each α – particle produces thousands of ions before being absorbed.

7. The range of alpha, α – particles in air (distance through which they can travel in air) depends upon the radioactive source producing it. At normal pressure in air, the range of α – particle varies from 3 to 8 cm.

8. Alpha, α – particles produces fluorescence in certain substances, like barium – plantinocyanide and zinc-sulphide.

9. Alpha, α – particles affected photographic plate slightly.

10. Alpha, α – particles are scattered while passing through thin metal foils. Most of the α – particles are scattered at small angles, but a few of them are scattered at an angle more than 900 also.

Velocity and energy of alpha particles:

The measurement of velocity and energy of α particles are precisely done with the help of magnetic spectrograph, and outline of which is shown in the diagram. the α-particles emitted from a radioactive sources are collimated in a narrow beam by slit. A strong magnetic field of known strength, applied in a direction perpendicular to the particle beam, deflects the particles through 180°. The scattering of alpha particles from the walls, top and bottom of the chamber is avoided by using a number of slits. Particles having the same radius and are therefore focused on a photographic plate placed at P.

Let B_o= Strength of the magnetic field

ℓ = charge on the particle

M= mass of the particle

V = velocity of the particle

r = radius of the circular path described by the particle under magnetic field B_o.

$$B_o \ell v = Mv^2 / r$$

$$v = e\, B_o.r/M$$

since e/M for an alpha particle is known , the velocity is obtained from the above formula if B_o and r are measured .

The energy E is given by,

$$E = \frac{1}{2} Mv^2$$

using this relation , the calculated energy is $2.074 \times 10^{-14}\, v^2$ Mev.

Gamow theory of alpha decay

As we have seen, the alpha separation energy is negative for heavy nuclei such as uranium, but these nuclei do not immediately decay. In fact, alpha decay mean lives vary from nanoseconds to gigayears. We have seen that the alpha particle can be regarded as trapped by a potential barrier. In order to escape into the environment, the alpha must tunnel through the barrier. This description of alpha decay, which also explains the wide range in lifetimes, was given by Gamow and was oe of the first successes of the new quantum theory (which introduced such counter-intuitive ideas as tunnelling).

Suppose we have a wave packet representing an alpha particle with mass m_α and kinetic energy E impinging on a square potential barrier of height V;SPMgt;E and width Δr . Then the transmission coefficent T is obtained from 2nd year quantum mechanics as

$$T \approx e^{-2\kappa\Delta r}$$

where $\kappa = \sqrt{2m_\alpha|V-E|}/\hbar$.

This can be extended to any barrier shape in the form of the WKB approximation:

$$T \approx \exp(-2\int_R^b \kappa(r)\,dr)$$

Here, R and b are the classical turning points of the motion inside and outside the barrier. We may take the barrier to be the sum of a square well nuclear potential of radius R, and a Coulomb potential arising from a charge within R,

$$\begin{aligned} V(r) &= 0 \qquad \text{for } r < R \\ &= \frac{1}{[4\pi\epsilon_0]}\frac{Z_\alpha Z_D e^2}{r} \qquad \text{for } r \geq R \end{aligned}$$

We can equate (aproximately) the energy release Q in the alpha decay to the kinetic energy E of the alpha particle and to the potential at the outer classical turning point.

$$Q \approx E = \frac{Z_\alpha Z_D e^2}{[4\pi\epsilon_0]b}$$

and hence determine b:

$$b = \frac{Z_\alpha Z_D e^2}{[4\pi\epsilon_0]Q}$$

Hence the integral over $\kappa(x)$ becomes

$$\begin{aligned} G &= \frac{2}{\hbar}\sqrt{2m_\alpha Q}\int_R^b \left[\frac{b}{r}-1\right]^{1/2} dr \\ &= \frac{2b}{\hbar}\sqrt{2m_\alpha Q}\left[\arccos\left(\frac{R}{b}\right)^{1/2} - \left(\frac{R}{b}\right)^{1/2}\left(1-\frac{R}{b}\right)^{1/2}\right] \\ &= \frac{4Z_\alpha Z_D e^2}{[4\pi\epsilon_0]\hbar v}\left[\arccos\left(\frac{R}{b}\right)^{1/2} - \left(\frac{R}{b}\right)^{1/2}\left(1-\frac{R}{b}\right)^{1/2}\right] \end{aligned}$$

where $Q = \frac{1}{2}m_\alpha v^2$ and the above expression for b has been used.

For thick barriers ($R/b \ll 1$ or $V(R) \gg Q$) we can approximate $\arccos\sqrt{Rb} \approx \pi/2 - \sqrt{R/b}$, and hence

$$\begin{aligned} G &\approx \frac{4Z_\alpha Z_D e^2}{[4\pi\epsilon_0]\hbar v}\left(\frac{\pi}{2} - 2\sqrt{\frac{R}{b}}\right) \\ &= \frac{Z_\alpha Z_D e^2}{2\epsilon_0 \hbar v} - \frac{1}{\hbar}\left(\frac{8Z_\alpha Z_D e^2 m_\alpha R}{\pi\epsilon_0}\right)^{1/2} \end{aligned}$$

The decay constant for alpha decay is thus

$$\begin{aligned} \lambda &= \lambda_0 e^{-G} \\ &= \lambda_0 \exp\left[-2\pi\frac{Z_\alpha Z_D}{\hbar v}\frac{e^2}{[4\pi\epsilon_0]} + \frac{1}{\hbar}\left(32 Z_\alpha Z_D m_\alpha R\frac{e^2}{[4\pi\epsilon_0]}\right)^{1/2}\right] \end{aligned}$$

where

$$\lambda_0 = \frac{v}{2R} \approx \frac{c}{2R}\sqrt{(}\frac{2Q_\alpha}{m_\alpha c^2}$$

Thus

$$\ln \lambda = \ln \lambda_0 + \frac{1}{\hbar}\left(32 Z_\alpha Z_D m_\alpha R \frac{e^2}{[4\pi\epsilon_0]}\right)^{1/2} - 2\pi \frac{Z_\alpha Z_D}{\hbar c}\frac{e^2}{[4\pi\epsilon_0]}\sqrt{\frac{m_\alpha c^2}{2Q_\alpha}}$$
$$= a' - \frac{b'}{\sqrt{Q_\alpha}}$$

The Geiger-Nutall equation is thus recovered. Note the extreme sensitivity of the decay constant on the energy in the above equation.

Alpha-Ray energies and fine structure of Alpha-Rays:

From the early measurements of energy and range of alpha particles, it was found that alpha particles emitted from a given nuclide have the same initial velocity and energy. But latter experiments showed that this is not the case. Rutherford, wood, Rosenblum etc. showed that the particles are emitted in groups of energies majority being emitted in one group and a smaller percentage in the long rage. For example ThC emits two groups of long range particles with energies 9.492Mev and 10.543 Mev as compared with energy of 8.780 Mev for the particles in the main group. The most recent magnetic spectrograph studies have shown the existence of 10.422 Mev group. For each million particles of the main group, there are about 40 particles in the 9.492 Mev group, 20 in the 10.422Mev group and 170 in the 10.543 Mev group. It was also shown by Roseblum that the normal alpha particles emitted by some nuclides fall into several closely spaced velocity groups through the difference is very small. This leads to the conclusion that alpha rays form a spectrum and have fine structure as well. The alpha particles spectra may be divided into three groups:

(a) spectra consisting of a single group or line

(b) spectra consisting of two or more discrete, closely spaced components with intensities of the same or of only slightly different order of magnitude.

(c) spectra consisting of a main group and groups of much higher energy particles, the latter containing, however, only a very small fraction of the number of particles in the main group.

Alpha disintegration energy:

We know that nucleons in nucleus are bound due to the presence of short-range nuclear force, also known as strong force which is attractive in nature. Nucleons mean number of protons and neutrons. But it's not meant that nucleus has only one force, there is also another kind of force which exists within the nucleus which is known as repulsive force. Its name comes from proton-proton repulsion. The range of the repulsive force is unlimited, where as the strong force has short range.

The nuclei which contain 210 numbers of nucleons or more are not stable in nature. The reason of it is that in such nuclei the strong force is hardly able to counterbalance the repulsive force because there exists large number of protons that have repulsive force between them and the range of repulsive force is unlimited. As a result Alpha decay occurs. In order to attain more stability such nuclei try to reduce their size.

But here is a question why Alpha decay occurs instead of individual protons or helium nuclei? The answer of it is that Alpha particles have high binding energy. In order to escape from nucleus, a particle must have kinetic energy, and only the mass of Alpha particle is sufficiently smaller than that of its constituent nucleons for such energy to be available.

By computing from the known masses of each particle and the parent and daughter nuclei, the energy is released known as disintegration energy, when various particles are emitted from large nuclei, and that energy is equal to the product of mass difference and square of speed of light. Here the mass difference means the difference in the masses of initial and final nuclei and the mass of particle.

When an Alpha particle emerges, the nucleus recoils with a small amount of kinetic energy, so we can say that the kinetic energy of emitted particle is not exactly equal to the disintegration energy. It can be shown from momentum and energy conservation that the kinetic energy of Alpha particle is related to disintegration energy and mass number, which is known as A, of original nucleus.

There are some cases in which the emission of Alpha particle is energetically possible, but it is not true for all type of nuclei. If Alpha decay occurs in Uranium that has 232 mass number and 92 proton number, energy will be released. If we want to emit a proton or helium nucleus from such nucleus, we must provide energy.

Long Range Alpha Particles:

The existence of long range alpha particles from some nuclei like RaC’ an ThC’ can be explained by assuming that the nuclide before emitting alpha particle exists in an excited state from some preceding disintegration (either by the emission of beta particle or gamma ray). Two possibilities occur in such case:

A gamma ray may first be emitted bringing the nucleus to its normal state then alpha disintegration takes place.

Or (2) the alpha particle may be emitted taking with it the excess energy of the excited nucleus.

The second process will naturally give the alpha particle energy much higher than the normal energy. The probability of the alpha particle following one of the above two processes is inversely proportional to the respective mean lives. But the mean life of an excited nucleus with gamma emission is very small- of the order of 10^{-12} secs, in comparison to the mean life of long range alpha particles. Thus the chances of the first phenomenon to take place are more in comparisonar to the other. But in certain cases like ThC′ and RaC′, the second process of alpha emission actually takes place which can be accounted for extremely short lives of the nuclei with respect to alpha particles of the order of 10^{-5} and 10^{-9} sec. these facts have been experimentally verified and found correct in case of ThC′. ThC′ is formed by beta integration of the ThC. This leaves the nuclide in an excited state giving rise to long range alpha particles and end product ThD.

Properties of beta particles:

A beta (β)- particle carries 1.6 x 10^{-19} C of negative charge, which is the charge on an electron.

The mass of β-particle is 9.1 x 10^{-31} kg, which is the same as that of electron.

The velocity of β-particles ranges from 33% to 99% of the velocity of light.

The β-particles ionize the gas through which they pass, but their ionizing power is only 1/100th that of α-particles.

Because of small mass, the penetrating power of β-particles is very large.

The β-particles can also produce fluorescence in certain substance like barium-plantinocyanide and zinc sulphide.

They affect a photographic plate.

They are deflected by electric and magnetic fields, showing that they carry negative charge.

General features of beta ray spectrum:

These are energetic electrons, they are relatively light and carry a single negative charge. Their mass is equal to the mass of the orbital electrons with which they are interacting and unlike the alpha particle a much larger fraction of its kinetic energy can be lost in a single interaction.

Their path is not so straightforward. The beta particles follow a very zig-zag path through absorbing material. This resulting path of particle is longer than the linear penetration (range) into the material.

Since they have very low mass, beta particles reach mostly relativistic energies.

Beta particles also differ from other heavy charged particles in the fraction of energy lost by radiative process known as the bremsstrahlung. Therefore for high energy beta radiation shielding dense materials are inappropriate.

When the beta particle moves faster than the speed of light (phase velocity) in the material it generates a shock wave of electromagnetic radiation known as the Cherenkov radiation.

The beta emission has the continuous spectrum.

A 1 MeV beta particle can travel approximately 3.5 meters in air.

Due to the presence of the bremsstrahlung low atomic number (Z) materials are appropriate as beta particle shields.

Paulis Hypothesis of Beta Decay:

Pauli introduced concept of third particle, a neutral particle which gets emitted in β^-decay. This particle has the generic name of Neutrino. The total energy is shared by 3 particles

The recoil nucleus

The Electron

The Neutrino

Because of its comparatively great mass, the recoil energy of Nucleus is very small and nearly all Kinetic Energy is shared between the Beta particle and the Neutrino.

In addition to laws of conservation of charge and energy, we must also apply the laws of conservation Linear and angular momentum to every nuclear process. Taking our reference system as the parent nucleus at rest, the vector sum of Linear Momenta of the recoil nucleus, the beta particle and neutrino must be zero.

To conserve angular momentum in β^-decay, we note that parent and daughter nuclei are isobars; i.e. they have equal number of nucleons. Hence, the total change in nuclear angular momenta will be either zero or an integral multiple of $\hbar$.

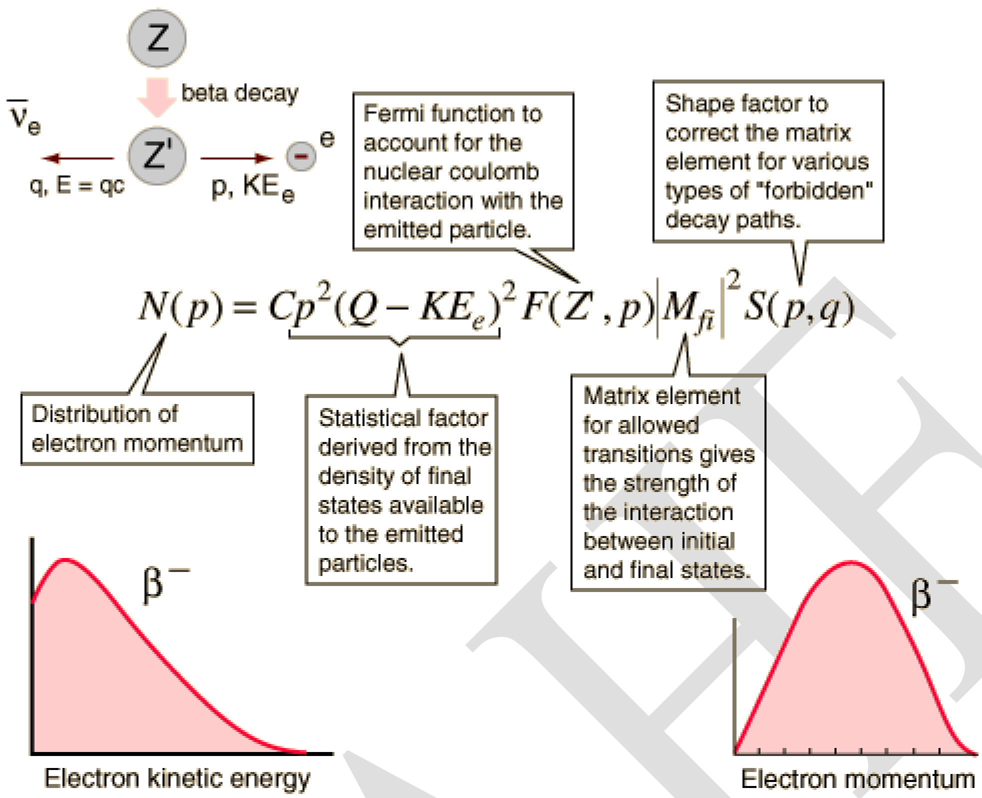
The beta particle has an intrinsic spin angular momenta of $1/2\hbar$.The vector sum of angular momenta of Neutrino and beta particle will be either zero or one in units of $\hbar$. The present accepted theory, which is supported by experimental evidence shows that there are two types of neutrino or two components of Neutrino. It has been found that the axis of spin of neutrino is parallel to its direction of motion; one type spins according to the left hand rule with respect to its direction of motion as its axis, the other component spins according to right hand rule. The first type is usually called neutrino represented by symbol ν, the second type is called antineutrino. The spin vector of neutrino points opposite to direction of its motion. The spin vector of anti neutrino points in the direction of its motion. Another way of saying this is that the helicity of neutrino is negative and that of anti neutrino is positive or one has right handed helicity and other has left handed helicity.

Fermi Theory of Beta Decay

In 1930, Wolfgang Pauli postulated the existence of the neutrino to explain the continuous distribution of energy of the electrons emitted in beta decay. Only with the emission of a third particle could momentum and energy be conserved. By 1934, Enrico Fermi had developed a theory of beta decay to include the neutrino, presumed to be massless as well as chargeless.

Treating the beta decay as a transition that depended upon the strength of coupling between the initial and final states, Fermi developed a relationship which is now referred to as Fermi's Golden Rule:

Straightforward in concept, Fermi's Golden Rule says that the transition rate is proportional to the strength of the coupling between the initial and final states factored by the density of final states available to the system. But the nature of the interaction which led to beta decay was unknown in Fermi's time (the weak interaction). It took some 20 years of work (Krane) to work out a detailed model which fit the observations. The nature of that model in terms of the distribution of electron momentum p is summarized in the relationship below.



Forms of interaction:

Gravitation is by far the weakest of the four interactions at the atomic scale, where electromagnetic interactions dominate. But the idea that the weakness of gravity can easily be demonstrated by suspending a pin using a simple magnet (such as a refrigerator magnet) is fundamentally flawed. The only reason the magnet is able to hold the pin against the gravitational pull of the entire Earth is due to its relative proximity. There is clearly a short distance of separation between magnet and pin where a breaking point is reached, and due to the large mass of Earth this distance is disappointingly small.

Electromagnetism is the force that acts between electrically charged particles. This phenomenon includes the electrostatic force acting between charged particles at rest, and the combined effect of electric and magnetic forces acting between charged particles moving relative to each other.

Electromagnetism is infinite-ranged like gravity, but vastly stronger, and therefore describes a number of macroscopic phenomena of everyday experience such as friction, rainbows, lightning, and all human-made devices using electric current, such as television, lasers, and computers.

Electromagnetism fundamentally determines all macroscopic, and many atomic levels, properties of the chemical elements, including all chemical bonding.

The strong interaction, or strong nuclear force, is the most complicated interaction, mainly because of the way it varies with distance. At distances greater than 10 femtometers, the strong force is practically unobservable. Moreover, it holds only inside the atomic nucleus.

After the nucleus was discovered in 1908, it was clear that a new force, today known as the nuclear force, was needed to overcome the electrostatic repulsion, a manifestation of electromagnetism, of the positively charged protons. Otherwise, the nucleus could not exist. Moreover, the force had to be strong enough to squeeze the protons into a volume that is about 10^{-15} m, much smaller than that of the entire atom. From the short range of this force, Hideki Yukawa predicted that it was associated with a massive particle, whose mass is approximately 100 MeV.

The weak interaction or weak nuclear force is responsible for some nuclear phenomena such as beta decay. Electromagnetism and the weak force are now understood to be two aspects of a unified electroweak interaction — this discovery was the first step toward the unified theory known as the Standard Model. In the theory of the electroweak interaction, the carriers of the weak force are the massive gauge bosons called the W and Z bosons. The weak interaction is the only known interaction which does not conserve parity; it is left-right asymmetric. The weak interaction even violates CP symmetry but does conserve CPT.

Selection rules:

We have seen that beta decay results from an interaction of the nucleus with the beta neutrino field. The action of the nucleus on the field is to create the electron and neutron. The beta transitions takes place under certain quantum conditions. The quantum numbers which govern such transitions' are generally total angular momentum and parity. Spin for a nucleus is defined as I=Angular momentum.

Parity is defined as the property that the wave function changes sign or not when the space coordinates(x,y,z) are transformed by inversion. If the wave function changes sign, the parity is odd or negative and if not the parity is even or positive.

Fermi and Gamow-Teller Transition

The beta decay is caused by the weak interaction. The weak interaction is very short range, because the mediate particles, the $W^{\pm}$ and Z^0 bosons are 80 GeV and 91 GeV respectively. The effective range is like 10^{-3} fm. So, the interaction can assumed to be a delta function and only the coupling constant matter. The Fermi coupling constant is

$$1.17 \times 10^{-11} (\hbar c)^2 \ \mathrm{MeV}^2$$

The fundamental process of beta decay is the decay of quark.

$$u \xrightarrow{W^+} d + e^+ + \nu_e$$

Since a pion is made from up and down quark, the decay of pion into position and electron neutrino is also due to weak interaction.

The Hamilton of the beta decay is

$$H_w(\beta^{\pm}) = G_V \tau_{\mp} + G_A \sigma \tau_{\mp}$$

where G_V is the vector coupling constant, the term is called Fermi transition. The $\tau_{\pm}$ is the isospin ladder operator. The beta+ decay changes the isospin from +1/2 (neutron) to -1/2 (proton). The G_A is the axial coupling constant, the term is called Gamow-Teller transition. σ is spin operator. Because of this operator, the Gamow-Teller transition did not preserve parity.

The G_A is different from G_V, which is caused by the effect of strong interaction. The Goldberger-Trieman relation

$$g_A = \frac{G_A}{G_V} = \frac{f_\pi g_{\pi N}}{M_N c^2} = -1.3$$

where $f_\pi \sim 93$ MeV is the pion decay constant. $g_{\pi N} \sim 14 \times 4\pi$ is the coupling constant between pion and nucleon. This, we can see the effect of the strong interaction, in which pion is the meson for strong nuclear force.

The transition probability can be estimated by Fermi-Golden rule

$$W(p_e) = \frac{2\pi}{\hbar} |\langle \psi_f | H | \psi_0 \rangle|^2 \rho(E_f)$$

the final state wavefunction

$$|\psi_f\rangle = \frac{1}{\sqrt{V}} e^{ik_e r} \frac{1}{\sqrt{V}} e^{ik_\nu r} |j_f m_f\rangle$$

$$e^{ikr} = \sum_L \sqrt{4\pi(2L+1)} i^L j_L(kr) Y_{L0}(\theta)$$

using long wavelength approximation, the spherical Bessel function can be approximated by the first term.

$$j_L(kr) \sim \frac{(kr)^L}{(2L+1)!!}$$

$$|\psi_f\rangle = \frac{1}{V}(1 + i\sqrt{\frac{4\pi}{3}} Y_{10} + \ldots)|j_f m_f\rangle$$

The first term 1, or L=0 is called allowed decay, so that the orbital angular momentum of the decayed nucleus unchanged. The higher order term, in which the weak interaction have longer range has very small probability and called L-th forbidden decay.

The density of state is

$$\rho(E_f) = \frac{V}{2\pi^2\hbar^7 c^3} F(Z, E_e) p_e^2 (E_0 - E_e)((E_0 - E_e)^2 - (m_\nu c^2)^2)^2$$

where the $F(Z, E_e)$ is the Fermi function.

The total transition probability is the integration with respect to the electron momentum.

$$W = \int W(p_e) dp_e = \frac{m_e^5 c^4}{2\pi^3 \hbar^7} f(Z, E_0) |M|^2$$

where $f(Z, E_0)$ is the Fermi integral. The half-life

$$T_{1/2} = \frac{\ln 2}{W}$$

To focus on the beta decay from the interference of the density of state, the ft-value is

$$ft = f(Z, E_0) T_{1/2} = \frac{2\pi^3 \hbar^7}{m_e^5 c^4} \frac{\ln 2}{|M|^2}$$

The ft-value could be difference by several order.

There is a super-allowed decay from $0^+ \to 0^0$ with same isospin, which the GT does not involve. an example is

$${}^{14}\mathrm{O} \to {}^{14}\mathrm{N} + e^+ + \nu_e$$

The ft-value is 3037.7s, the smallest of known.

transition	L	$\log_{10} ft_{1/2}$	ΔJ		ΔT	$\Delta \pi$
			Fermi	GT		
Super allowed		3.1 ~ 3.6	$0^+ \to 0^+$	not exist	0	no
allowed	0	2.9 ~ 10	0	(0), 1	0, 1 ; $T_i = 0 \to T_f = 0$ forbidden	no
1st forbidden	1	5 ~ 19	(0),1	0, 1, 2	0,1	yes
2nd forbidden	2	10 ~18	(1), 2	2, 3		no
3rd forbidden	3	17 ~ 22	(2), 3	3, 4		yes
4th forbidden	4	22 ~ 24	(3), 4	4, 5		no

The () means not possible if either initial or final state is zero. i.e $1^- \to 0^+$ is not possible for 1st forbidde

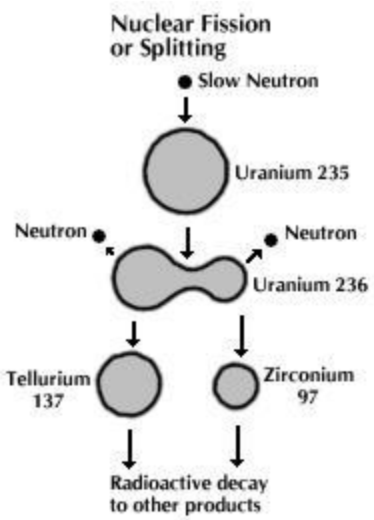
KARPAGAM ACADEMY OF HIGHER EDUCATION,COIMBATORE-21					
DEPARTMENT OF PHYSICS					
CLASS:I MSC PHYSICS					
NUCLEAR PHYSICS (17PHP203)					
MULIPLE CHOICE QUESTIONS					
Unit II					
Questions	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Answer**
Which of the following have the highest ionisation power?	α-rays	β-rays	γ-rays	x-rays	α-rays
The emission of α-particles in terms of the penetration of nuclear potential barrier is called	Shading of the nucleus	Tunneling of the nucleus	Discharging of the nucleus	None of these	Tunneling of the nucleus
Radioactivity is	Irreversible process	Spontaneous process	Self disintegration process	All of the above	All of the above
Which of the following is the alpha particle?	electron	$0n^1$	$1H^1$	$2He^4$	$2He^4$
Which of the following about the gamma ray is true?	It carries a positive charge	It carries a negative charge	It can be deflected by a magnetic field	It has zero rest mass and a neutral charge	It has zero rest mass and a neutral charge
The most probable process after an Internal conversion electron is ejected from an atom with a high ato	Atom emits one or several X-rays	Nucleus emits a γ-rays	Nucleus emits an electron	Nucleus emits a positron	Atom emits one or several X-rays
If the mass of a radioactive sample is doubled, the activity of the sample will	Increase	Decrease	Remains the same	None of these	Increase
Expected types of gamma ray transition between states of odd A nuclei g9/2→ g1/2	E1	M4	E4	E3	E3
The minimum energy of an antineutrino to produce the reaction will be, when	The neutron and positron are moving in opposite side	The neutron is at rest	The positron is at rest	The neutron and positron are both emitted with zero kinetic energy	The neutron and positron are both emitted with zero kinetic energy
A nucleus is in excited state. If it is not able to de-excite itself by gamma emission, it can de-excite throu	Electron capture	Internal conversion	Alpha decay	Beta decay	Internal conversion
To penetrate the coulomb barrier of a light nucleus, a proton must have a minimum energy of the order o	1GeV	100MeV	10MeV	1MeV	1MeV
A free neutron decays into a proton with the emission of an electron and a third particle to conserve the	Neutrino	Gamma ray	Anti-neutrino	Neutron	Anti-neutrino
In fermi's theory of β-decay the important thing is	To find out a value of β-transformation	To calculate the probability of β-transformation	To find out parity of β-transformation	None of these	To calculate the probability of β-transformation
β-particle spectrum is found to be continuous upto a certain maximum because	β-particle is emitted with continuous energy	β-particle carries only a part of the energy leaving the nucleus in an excited state	With β-particle a another charged particle is emitted	With β-particle a chargeless particle is also emitted so that the momentum and energy is distributed among these two particles and the	With β-particle a chargeless particle is also emitted so that the momentum and energy is distributed among these two particles and the recoiling nucleus
The total energy of the γ-ray when an electron and a positron of energy 6MeV get annihilated is	1.02MeV	0.511MeV	13.02MeV	40MeV	13.02MeV
A sensitive way to measure the mass of the electron neutrino is to measure	The angular distribution in electron-neutrino scattering	The electron energy spectrum in beta decay	The neutrino flux from the sun	None of these	The electron energy spectrum in beta decay
When a neutron is converted into a proton	Only an electron is produced	One electron and a neutrino are produced	One electron and an antineutrino are produced	One electron and a proton are produced	One electron and an antineutrino are produced
The half-life period of a radioactive sample depends upon	Temperature	Pressure	Nature of the substance	All of the above	Nature of the substance
Which of the following is correct statement?	β-rays are the same as cathode rays	Γ-rays is high energy neutrons	A-particles are singly ionized helium atom	Protons and neutron have exactly the same n	β-rays are the same as cathode rays
Why is β- decay more common than β+ decay among naturally occurring radioactive elements?	The binding of positrons in nuclei is greater than that of elec	Electrons are more easily excited by γ rays than are positrons	Alpha (α) decay leaves nuclei neutron-rich	Positrons cannot exist in ordinary matter	Alpha (α) decay leaves nuclei neutron-rich
When an α-particle captures an electron, it becomes	Hydrogen atom	A helium atom	A helium ion	β-particle	A helium ion
The penetrating powers of γ-rays are	Minimum	10000 times of α-rays and 100 times of β-rays	1000 times of β-rays	None of these	10000 times of α-rays and 100 times of β-rays
The phenomenon of pair production is	Production of an electron and a positron from γ-rays	Ejection of an electron from a nucleus	ionisation of a neutral atom	None of these	Production of an electron and a positron from γ-rays
Who developed theory to explain continuous β-ray neutrino theory	Rutherford	Fermi	Bohr	Goldstein	Fermi
A process of interaction of an electron with a x-ray photon in which the incident photon gives a part of it	Compton effect	Bragg's law	Raman effect	None of these	Compton effect
Whenever an electron and positron come very close to each other and γ photons are produced. This phe	Pair annihilation	Pair production	Meson production	None of these	Pair annihilation
In the neutrino the spin and angular momentum vector are	oppositely directed	aligned together	aligned or oppositely directed	none of the above	oppositely directed
The long range alpha particles exist in nuclei like	RaC' and ThC'	RaA	RaF	Rn	RaC' and ThC'
Which of the following alpha particle spectra consist of a single group	RaA	RaF	Rn	All the above	All the above
Who pointed out that a particle inside the nucleus may escape with energy much less than its potential er	Gurney	Condon	Gamow	All of these	All of these
In the decay $O^{14} \rightarrow N^{14*} + e^{+} + \nu$ ($0^{+} \rightarrow 0^{+}$)	Allowed by F-selection rules	Allowed by G-T selection rules	Forbidden by F-selection rules	Forbidden by F-selection rules and G-T selection rules	Allowed by F-selection rules
A spin-1/2 particle A undergoes the decay A→B+C+D Where it is known that B & C are also spin-1/2	1/2, 1, 3/2, 2, 5/2, 3,….	0, 1	½ only	½, 3/2,5/2,7/2,…	½, 3/2,5/2,7/2,…
Rubidium $_{37}Rb^{87}$ is a naturally occurring nuclide that undergoes beta-minus decay. The nuclide, which is	$38Kr^{87}$	$37Rb^{88}$	$38Sr^{87}$	$36Sr^{87}$	$38Sr^{87}$
Mean life of a radioactive atom between two successive disintegrations is inversely proportional to	energy	frequency	wavelength	none of the above	energy
Which of the following is the alpha particle?	e_(−1	n_0^1	H_1	〖He〗	〖He〗
Which of the following is the β^- particle?	e_(+1)	e_(−1)	n_0^	H_1	e_(-
Which of the following is the β+ particle?	e_(	e_(−1	n_0^	H_1^1	e_(+1)
What is the missing element from the following equation					
What is the missing element from the following equation $^{14}C_6 \rightarrow ? + {}^{0}e_{-1}$	$13N_7$ (86^220)Rn	$12C_6$ (86^228)Rn	$16O_8$ (86^222)Rn	$14N_7$ (86^230)Rn	$14N_7$
The nuclide ^{244}Pu (Z=94) is an alpha emitter. It will decay into	^{240}Np (Z=93)	240U (Z=92)	^{248}Cm (Z=96)	^{244}Am (Z=95)	240U (Z=92)
Expected types of gamma ray transition between states of odd A nuclei $g_{9/2} \rightarrow g_{1/2}$	E1	M4	E4	E3	E3
The minimum energy of antineutrino of 1.80MeV to produce inverse beta decay reaction is [Mn=939.57	1.8MeV	8MeV	40MeV	80keV	1.8MeV
The following equation is an example of $He^4 \rightarrow Li^6$ and $\beta^- + \nu^-$	Gamow Teller selection rule	Pauli spin rule	Fermi selection rule	Direc selection rule	Gamow Teller selection rule
The selection rule for γ-rays photon is	ΔJ=0 or ΔJ=1	E_f=E_i=hω	ΔS=0 to ΔS=1	None of these	E_f=E_i=hω
By capturing an electron,$^{55}Mn_{25}$ transforms into $^{54}Cr_{24}$ releasing	A neutrino	An antineutrino	An α-particle	A positron	A neutrino
The Internal conversion coefficient is defined as	N_e/N_γ	N_γ/N_e	N/N_e	sqrt(N/Ne)	N_e/N_γ
In the β-decay of neutron ,n→p+e^-+(ν_e)¯ the anti-neutrino ν¯, escapes detection. Its existence is inferre	Energy distribution of e-s	Angular distribution of electrons	Helicity distribution of electrons	Forward-backward asymmetry of electrons	Forward-backward asymmetry of electrons
If R is the range of α-particles and λ is decay constant, then Geiger Nuttal Law is	Logλ=a+R	λ=a+logR	logλ=ae^R	logλ=a+blogR	logλ=a+blogR
The equation hν=$_1\beta^0$ +$_1\beta^0$ represents	Meson production	Pair production	photon production	None of these	Pair production
$1H_1$+ $^0e_{-1}$ →$^1n_0$ is an example of	negatron emission	positron emission	orbital electron capture	all of the above	orbital electron capture
The long range alpha particles exist in nuclei like	RaC' and ThC'	RaA	RaF	Rn	RaC' and ThC'
Almost all the substances undergoing natural radioactivity are found to emit either	α and electron	β and α	α, β and γ	None of the above	α, β and γ
nuclei like RaC' and ThC' exists as	short range alpha-particles	long range alpha particles	short or long range alpha particles	none of the above	long range alpha particles
Spontaneous alpha disintegration energy is obtained by multiplying………………of alpha particle by the	potential energy	kinetic energy	potential and kinetic energy	none of the above	kinetic energy
Prepared by Dr. B. Janarthanan, Associate Professor, Department of Physics, KAHE					

UNIT-III

SYLLABUS

Nuclear models: Liquid drop model - Bohr Wheeler theory of fission - Condition for spontaneous fission - Activation energy-Seaborg's expression - Shell model: Explanation for magic numbers - Prediction of shell model -Prediction of spin and parity - Nuclear statistics - Magnetic moment of nuclei - Schmidt lines-Nuclear isomerism - Collective model: Explanation of Quadrapole moments - Prediction of sign of electric quadrupole moments. Optical model: Nilsson model - Elementary ideas

Liquid Drop Model of Nucleus:



One of the first models which could describe very well the behavior of the nuclear binding energies and therefore of nuclear masses was the mass formula of von Weizsaecker (also called the semi-empirical mass formula – SEMF), that was published in 1935 by German physicist Carl Friedrich von Weizsäcker. This theory is based on the liquid drop model proposed by George Gamow.

According to this model, the atomic nucleus behaves like the molecules in a drop of liquid. But in this nuclear scale, the fluid is made of nucleons (protons and neutrons), which are held together by the strong nuclear force. The liquid drop model of the nucleus takes into account the fact that the nuclear forces on the nucleons on the surface are different from those on nucleons in the interior of the nucleus. The interior nucleons are completely surrounded by other attracting nucleons. Here is the analogy with the forces that form a drop of liquid.

In the ground state the nucleus is spherical. If the sufficient kinetic or binding energy is added, this spherical nucleus may be distorted into a dumbbell shape and then may be splitted into two fragments. Since these fragments are a more stable configuration, the splitting of such heavy nuclei must be accompanied by energy release. This model does not explain all the properties of the atomic nucleus, but does explain the predicted nuclear binding energies.

The nuclear binding energy as a function of the mass number A and the number of protons Z based on the liquid drop model can be written as: This formula is called the Weizsaecker Formula (or the semi-empirical mass formula). The physical meaning of this equation can be discussed term by term.

Bohr wheeler theory-condition for spontaneous fission:

The discovery of fission was a seed dropped on fertile ground. With remarkable speed, Niels Bohr and John Wheeler published a theory of the dynamic process of fission. With equal speed, physicists grasped its practical potentialities.

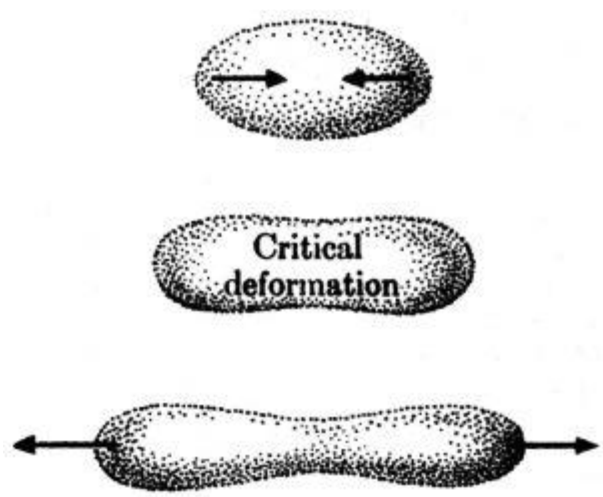
In assessing the prospects of large-scale energy release by means of fission, three basic questions needed to be answered. The first, the easiest, and the least important was: How much energy is released in a fission event? This is a question that Lise Meitner could answer in December 1938, even as she and her nephew Otto Frisch were postulating the existence of fission. She knew the overall pattern of nuclear binding energies from the lightest to the heaviest elements, and reckoned that the fission of a uranium nucleus should release about 1 MeV per nucleon, or about 200 MeV per fission event—a prediction soon verified by experiment. The reason the precise magnitude of the energy release is not very important is that this energy, quickly transformed to heat, is irrelevant to the nuclear course of events. Although it is obviously of great practical significance, fission energy contributes nothing to the chain-reaction process.

The second question was: Which nuclei are most fissionable? and the third: How many neutrons are emitted in a fission event? Once these questions were answered, it could be decided whether a fission chain reaction could be self-sustaining, and if so, with what isotopes.

Nuclear fission would have been a dramatic discovery at any time. Coming as it did on the eve of a major war and in the midst of a period of persecution of Jews in Germany, its drama was heightened. The persecution drove many of Europe's leading scientists to the United States, and the war drove fission work into secrecy. Half a dozen years after the discovery of fission, the United States emerged as the scientific leader of the world, atomic energy was a household word, and ties forged between science and government set a pattern for the support of large-scale research that has lasted to the present day.

One small act in the total drama of fission was the theoretical work of Bohr and Wheeler in 1939. Using the liquid-droplet model of the nucleus, they provided an explanation of the fission process and predicted which nuclei should be most fissionable (the second question above). Apprised of the ideas of Frisch and Meitner just before leaving Copenhagen early in January, 1939, Bohr pondered the idea of nuclear fission all the way across the Atlantic. By the time he greeted his young colleague John Wheeler on the pier in New York, he had a half-completed theory of fission in his mind (and therefore no inclination to question the validity of the evidence for fission). After five months of effort in Princeton, Bohr and Wheeler submitted for publication a paper that provided both a mathematical theory and a pictorial model of fission. (It was published on August 1, 1939, the day that Hitler's troops marched into Poland, launching World War II.)

In essence, the Bohr-Wheeler theory is simple. Two forces are at work in a heavy nucleus: the nuclear force, holding the nucleus together, and the Coulomb electrical force, tending to blow the nucleus apart (see the figure below). For all the nuclei we know, the nuclear force is in control, but for the heaviest known nuclei, it is only barely in control. The problem of the fissionability of a nucleus can be posed this way: If a nucleus is stretched into an elongated shape, what is greater—the repulsive electric force tending to push it into an even more elongated shape, or the attractive nuclear force tending to restore it to a spherical or near spherical shape? If a nucleus like uranium is slightly distorted from its normal shape, the nuclear force wins out, tending to restore it to its original shape. If it is distorted much further, the electric force wins out and it splits in two (or occasionally three). Between these two regions is an energy barrier. In slow spontaneous fission (a rarity in naturally occurring elements), this barrier can be penetrated, just as a barrier is penetrated in alpha decay. For the rapid fission that occurs in reactors or bombs, the barrier must be surmounted. The magnitude of the energy barrier to be overcome depends sensitively on the relative magnitude of two energies of opposite sign: the Coulomb (electric) energy, arising from the mutual repulsion of the protons; and the surface-tension energy, arising from the nuclear forces. From approximate considerations of these energies, one can extract a significant parameter, which measures nuclear fissionability.



The mechanism of fission. Attractive

Consider first the electric energy. Associated with each pair of protons is an energy ke^2/r, where r is an average distance between the two protons. The larger the nucleus, the larger this average separation, in direct proportion to the nuclear radius R. Therefore the Coulomb energy of a pair of protons is proportional to 1/R. The number of distinct proton pairs is equal to Z(Z – 1), since each of the Z protons can pair off with Z – 1 other protons. Therefore, the total Coulomb energy is proportional to Z(Z – 1)/R, or approximately Z^2/R if Z is large:

$$E_{\text{coulomb}} \sim \frac{Z^2}{R}.$$

The other relevant energy is the nuclear surface-tension energy. It is proportional to the surface area of the nucleus, or to the square of the nuclear radius:

Esurface ~ R^2 .

The ratio Ecoulomb/Esurface is then proportional to Z^2/R^3. Since the cube of the nuclear radius is proportional to the nuclear volume, which in turn is proportional to the number of nucleons in the nucleus1 (the mass number A), one can write

$$\frac{E_{\text{coulomb}}}{E_{\text{surface}}} \sim \frac{Z^2}{A}.$$

Bohr and Wheeler recognized that this ratio, Z_2/A, is an important parameter of fission. The greater its magnitude, the more nearly does the repulsive electric force win out over the attractive nuclear force, and the more easily fissionable is the nucleus. Consider nuclei of the two principal isotopes of uranium, to each of which a neutron is added:

$U_{235} + n = U_{236}$: $Z^2/A = 35.9$

$U_{238} + n = U_{239}$: $Z^2/A = 35.4$.

Because of this small difference, the fission energy barrier is slightly lower for U_{236} than for U_{239}. Another and even more important contributor to the distinction between the fissionability of these two isotopes is the somewhat greater excitation energy provided when U_{235} absorbs a neutron than when U_{238} absorbs a neutron. This is attributable, ultimately, to the exclusion principle, which favors an even number of protons and of neutrons. In U_{235}, the absorption of a slow neutron provides enough energy to surmount the fission barrier. In U_{238} it does not. The difference is all-important. Most of the neutrons emitted during fission are of relatively low energy, capable of inducing further fission in U_{235} but not in U_{238}.

"Magic Numbers" in Nuclear Structure:

It is found that nuclei with even numbers of protons and neutrons are more stable than those with odd numbers. In particular, there are "magic numbers" of neutrons and protons which seem to be particularly favored in terms of nuclear stability:

2,8,20,28,50,82,126

Magic Numbers

Nuclei which have both neutron number and proton number equal to one of the magic numbers can be called "doubly magic", and are found to be particularly stable.

The existence of these magic numbers suggests closed shell configurations, like the shells in atomic structure. They represent one line of reasoning which led to the development of a shell model of the nucleus. Other forms of evidence suggesting shell structure include the following.

Enhanced abundance of those elements for which Z or N is a magic number.

The stable elements at the end of the naturally occurring radioactive series all have a "magic number" of neutrons or protons.

The neutron absorption cross-sections for isotopes where N = magic number are much lower than surrounding isotopes.

The binding energy for the last neutron is a maximum for a magic neutron number and drops sharply for the next neutron added.

Electric quadrupole moments are near zero for magic number nuclei.

The excitation energy from the ground nuclear state to the first excited state is greater for closed shells.

Predictions of the Shell model

Angular Momentum: As with all single particle energy level models, the Shell Model predicts that all even-even nuclei will have zero angular momentum. An odd A nucleus will have the angular momentum of the odd nucleon. For example -

Nuclide	Z	N	Shell Model	Observed Ground State
17O	8	9	l = 2; j = 5/2	I = 5/2; + parity
17F	9	8	l = 2; j = 5/2	I = 5/2; + parity
43Se	21	22	l = 3; j = 7/2	I = 7/2; - parity
209Pb	82	127	l = 4; j = 9/2	I = 9/2; + parity
209Bi	83	126	l = 5; j = 9/2	I = 9/2; - parity

Excited states of such single particle nuclei follow the Shell Model up to about 2 MeV above the ground state but then excitations of the core complicate the energy level picture. The model makes no predictions for odd-odd nuclei.

Magnetic Moments: Odd A nuclei should have the moment of the odd nucleon.

$\mu/\mu_N = (j - 1/2)g_l + g_s$ if $l = j - 1/2$ for odd nucleon

$\mu/\mu_N = \{(j + 3/2)g_l - g_s\}[j/(j + 1)]$ if $l = j + 1/2$ for odd nucleon

$g_l = 1$ for the proton, 0 for the neutron: $g_s = 2.79$ for the proton, -1.91 for the neutron. These are the so called Schmidt Limits for nuclear magnetic moments and most actual values lie between them. This can be explained in terms of a mixing of states such as that we have already seen in the case of the deuteron.

Electric Quadrupole Moments: If this moment were just due to the odd proton it should be given by $Q \sim -R^2(2j - 1)/(2(j + 1))$ where j is the angular momentum quantum number of the odd particle. For even-even nuclei it should be about zero and should change sign on going through the shell closure. Some examples are

Nuclide	Z	N	Character	Qobs(QSM)	Ratio
17O	8	9	+1 neutron; j = 5/2	-2.6(-0.1)	20
39K	19	20	- 1 proton; j = 3/2	+5.5(+5.0)	1
175Lu	71	104	mid shell; j = 7/2	+560(-25)	-20
209Bi	83	126	+1 proton; j = 9/2	-35(-30)	1

The Q are expressed in $(fm)^2$ thus the numbers have to be multiplied by the electronic charge to obtain the actual quadrupole moment. There are clear deviations from the Shell Model predictions (QSM):

Odd neutron nuclei have about the same Q as odd proton ones.

Nuclei with atomic mass number in the ranges 150 to 190 and greater than 200 have very large quadrupole moments. This is an outstanding failure of the model.

Nuclear isomerism:

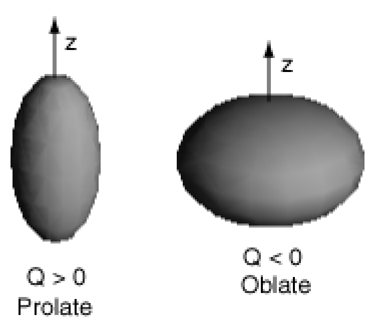
The existence of excited states of atomic nuclei with unusually long lifetimes. If the lifetime of aspecific excited state is unusually long, compared with the lifetimes of other excited states in th esame nucleus, the state is said to be isomeric. The definition of the boundary between isomeric an dnormal decays is arbitrary, and the term is therefore used loosely.

The rate at which thisprocess occurs is determined largely by the spins, parities, and excitation ener gies of the decayingstate and of those to which it is decaying. In particular, the rate is extremely sen sitive to thedifference in the spins of initial and final states and to the difference in excitation energi es. Bothextremely large spin differences and extremely small energy differences can result in a slo wing ofthe γ-

ray emission by many orders of magnitude, resulting in some excited states having unusuallylong li fetimes and therefore being termed isomeric.

Electric Quadrupole Moments of Nuclei:

The nuclear electric quadrupole moment is a parameter which describes the effective shape of the ellipsoid of nuclear charge distribution. A non-zero quadrupole moment Q indicates that the charge distribution is not spherically symmetric. By convention, the value of Q is taken to be positive if the ellipsoid is prolate and negative if it is oblate.



Classical definition

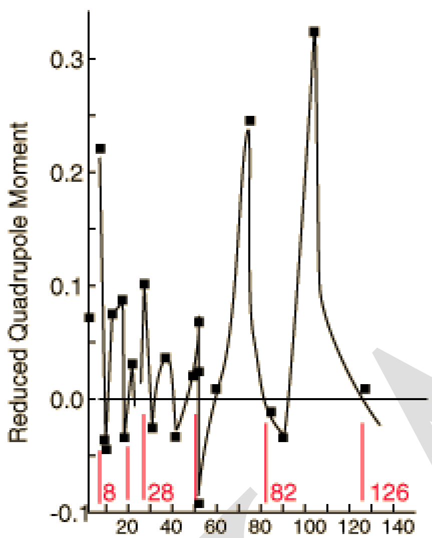
$$Q_0 = \int \rho(3z^2 - r^2)dV$$

$$Q = \frac{3K^2 - I(I+1)}{(I+1)(2I+3)} Q_0$$

Quantum measurement

The quantity Q_0 is the classical form of the calculation represents the departure from spherical symmetry in the rest frame of the nucleus. The expression for Q is the quantum mechanical form which takes takes into account the nuclear spin I and the projection K in the z-direction.

One of the expectations of the shell model for the nucleus is that for closed shells the nuclear charge is spherically symmetric. If a nucleus is not spherically symmetric, it will have a non-zero electric quadrupole moment, so the measurement of the quadrupole moment is a test of the shell theory. Since the quadupole moment depends upon the size and charge of the nucleus, a better comparison is obtained by normalizing for those factors, giving what is called a "reduced quadrupole moment". A plot of measured values shows that magic numbers of neutrons or protons correlate with near-zero quadrupole moments.



Quadrupole measurements for odd-A nuclei. The horizontal axis is either neutron number or proton number, whichever is odd.

For a shell model, those nuclei with closed shells should be spherically symmetric and have no quadrupole moment.

Electric quadrupole moments of nuclei can be measured brom hyperfine splitting of atomic spectral lines, from quadrupole hyperfine splitting of molecular rotational spectra, and other spectroscopic techniques.

The Collective Model (explanation of qudrapole moment):

The Shell Model has its shortcomings. This is particularly true for heavier nuclei. We have already seen that the Shell Model does not predict magnetic dipole moments or the spectra of excited states very well.

One further failing of the Shell Model are the predictions of electric quadrupole moments, which in the Shell Model are predicted to be very small. However, heavier nuclei with A in the range 150 - 190 and for A > 220, these electric quadrupole moments are found to be rather large.

The failure of the Shell Model to correctly predict electric quadrupole moments arises from the assumption that the nucleons move in a spherically symmetric potential. The Collective Model generalizes the result of the Shell Model by considering the effect of a non-spherically symmetric potential, which leads to substantial deformations for large nuclei and consequently large electric quadrupole moments.

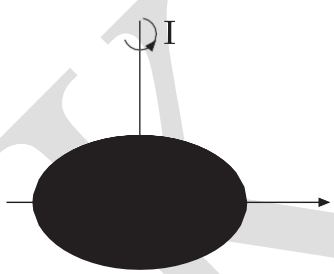
One of the most striking consequences of the Collective Model is the explanation of low-lying excited states of heavy nuclei. These are of two types

Rotational States: A nucleus whose nucleon density distributions are spherically symmetric (zero quadrupole moment) cannot have rotational excitations (this is analogous to the application of the principle of equipartition of energy to monatomic molecules for which there are no degrees of freedom associated with rotation). On the other hand a nucleus with a non-zero quadrupole moment can have excited levels due to rotational perpendicular to the axis of symmetry.

For an even-even nucleus whose ground state has zero spin, these states have energies

$$E_{\rm rot} = \frac{I(I+1)\,k^2}{2\mathrm{I}}$$

where **I** is the moment of inertia of the nucleus about an axis through the centre



perpendicular to the axis of symmetry. It turns out that the rotational energy levels of an even-even nucleus can only take even values of I. For example the nuclide ^{170}Hf (hafnium) has a series of rotational states with excitation energies

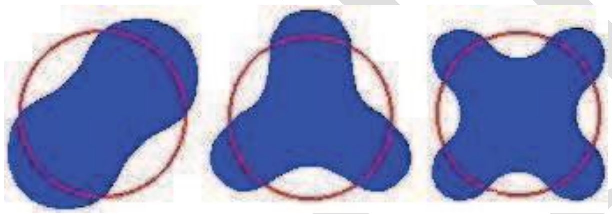
E (KeV) : 100, 321, 641

These are almost exactly in the ratio 2 × 3 : 4 × 5 : 6 × 7, meaning that these are states with rotational spin equal to 2, 4, 6 respectively. The relation is not exact because the moment of inertia changes as the spin increases.

We can extract the moment of inertia for each of these rotational states from eq.(5.6.2). We could express this in SI units, but more conveniently nuclear moments of inertia are quoted in $MeV/c^2\ fm^2$, with the help of the relation

$$k\, c = 197.3 \text{ MeV fm.}$$

- For odd-A nuclides for which the spin of the ground state I_0 is non-zero, the rotational levels have excitation levels of where I can take the values $I_0 + 1$, $I_0 + 2$ etc. For example the first two rotational excitation energies of ^{143}Nd (neodynium), whose ground state has spin, have energies 128 KeV and 290 KeV. They correspond to rotational levels with nuclear spin respectively. Shape oscillations: These are modes of vibration in which the deformation of the nucleus oscillates - the electric quadrupole moment oscillates about its mean value. It could be that this mean value is very small, in which case the nucleus is oscillating between an oblate and a prolate spheroidal shape. It is also possible to have shape oscillations with different shapes



The small oscillations about the equilibrium shape perform simple harmonic motion. The energy levels of such modes are equally spaced. Thus an observed sequence of equally spaced energy levels within the spectrum of a nuclide is interpreted as a manifestation of such shape oscillations.

KARPAGAM ACADEMY OF HIGHER EDUCATION,COIMBATORE-21
DEPARTMENT OF PHYSICS
CLASS:I MSC PHYSICS
NUCLEAR PHYSICS (17PHP203)
MULIPLE CHOICE QUESTIONS

Unit - III

QUESTIONS	opt1	opt2	opt3	opt4	answer
Which model has been very successful in e	Shell model	Liquid drop model	Bohr model	Collective model	Shell model
Shell model fails to explain	The large electric quadrupole	The ground states of odd nuclei	The excited states of even-ev	All the above	All the above
Possible reason for the discrepancy in shell	magnetic dipole moments of t	nuclei is considered as spherical	nucleus is considered as sphe	1 & 2	1 & 2
The deformation of the nucleus is attributed	Magnetizing action	polarizing action	electrolyzing action	none of the above	polarizing action
Standing waves will occur whenever the ra	4	3	2	1	4
The nucleons move in a potential which is	Four	one	two	three	two
Which model is the combination of liquid c	Collective model	Unified model	optical model	Super-conductivity model	Collective model
The unified model was developed by	Bohr	Mottelson	Bohr and Mottelson	Rainwater	Bohr and Mottelson
Which is the hybrid of liquid drop model a	Collective model	optical model	Unified model	none of the above	Unified model
In which model the shell model potential is	Collective model	Liquid drop model	Optical model	unified model	unified model
The mathematical theory of unified model	Nilsson	Rainwater	Davydov and Chaban	Bohr and Kalcker	Nilsson
Nilsson model has been successful in descr	Heavier deformed nuclei	odd nuclei	both a & b	even nuclei	both a & b
The optical model of the nucleus is develop	Scattering of light	Reflection	Diffraction	None of the above	Scattering of light
The collective motion of the nucleons in a	rotational	vibrational	rotational or vibrational	electronic	rotational or vibrational
Which nucleon needs large energy for excit	Paired nucleon	unpaired nucleon	odd neutron	odd proton	Paired nucleon
Odd nuclei consists of one or two	unpaired nucleons	paired nucleons	unpaired neutron and proton	All of the above	unpaired nucleons
The series of rotational levels, beginning w	J=2,4,6	J=1,2,3	J=1,3,5	J=0,1,2,3,4	J=2,4,6
Negative parity have only …………………	even values	odd values	even or odd values	zero	odd values
The study of nuclear shell model introduce	molecular physics	quantum physics	Atomic physics	Thermal physics	Atomic physics
Which model introduces many new ideas f	Unified model	Liquid drop model	Collective model	Nilsson model	Collective model
The deviations of ……………………… I	dipole moment	magnetic moment	orbital moment	spin moment	magnetic moment
Who suggested in odd A nuclei by consider	Bohr and Mottelson	J. Rainwater	Bohr	Nilsson	J. Rainwater
The λ=2 quadrupole surface vibrational sta	one phonon state	two phonon state	four phonon state	six phonon state	one phonon state
The Nilsson model has been successful in c	Properties of heavier deforme	Properties of odd nuclei	Properties of even nuclei	a & b	a & b
The amount of dimming the intensity can b	refractive index	Absorption coefficient	refractive index and Absorpti	Extinction coefficient	refractive index and Absorption coefficient
The λ=1 motion implies …………………	rotational	vibrational	translational and rotational	translational	translational
Magic numbers are	2,8,20,28,50,82,126	2,8,20,28,40,50,82	2,8,20,40,70,112,168	20,40,50,82,126	2,8,20,28,50,82,126
In which model, it is assumed that the nucl	Extreme single particle model	Collective model	unified model	Nilsson model	Extreme single particle model
The closure of a shell for the harmonic osci	8,18,20,34,40 and 50	2,8,20,40,70,112 and 168	18,30,50, 82 and 126	2,8,20,28,50,82,126	2,8,20,40,70,112 and 168
The shell closes at particle numbers 2,8,18,	Square-well of infinite depth	harmonic oscillator potential	spin-orbit potential	finite square-well	Square-well of infinite depth
Tin has ……………	Ten stable isotopes	six stable isotopes	unstable isotopes	none of the above	Ten stable isotopes
Which model is the forerunner of the collec	Shell model	Liquid drop model	Fermi gas model	unified model	Liquid drop model
Which of the following property of the liqu	surface tension force of a liqu	molecules in a liquid	latent heat of vaporisation	Molecules attract one anothe	Molecules attract one another at distances larger than the dimensions of the electron shells
The motion of the molecules in the liquid a	Classical and Quantum	Quantum and classical	molecular and Classical	molecular and Quantum	Classical and Quantum
If the forces between the external nucleons	oblate spheroid	prolate spheroid	spherical	octupole	prolate spheroid
If the forces between the external nucleons	oblate spheroid	prolate spheroid	spherical	octupole	oblate spheroid
Prof. Rainwater, Prof. A.Bohr and Prof. M	Nilsson model	Collective model	Optical model	Liquid drop model	Collective model
Nilsson found that, upon deformation of th	2(2j+1)	(2j+1)/2	j+1	2j+1	(2j+1)/2
The nuclear isomerism has been successful	Liquid drop model	unified model	single particle model	Fermi gas model	single particle model
Nuclei with N or Z near the end of a shell a	three	two	seven	four	four
The curves of magnetic moment are known	spectral lines	Schmidt lines	Balmer lines	None of the above	Schmidt lines
The mechanism of nuclear fission was first	liquid drop model of the nucle	Shell model	Optical model	Unified model	liquid drop model of the nucleus
Angular momenta and parity for N^{16} is	$½^-$	$5/2^+$	2^-	3^-	2^-
The expected shell model spin and parity a	$3/2^+$	$3/2^-$	$5/2^+$	$½^-$	$3/2^-$
Parity corresponding to	electron is even but that of pr	electron is odd but that of proto	electron and proton is odd	electron and proton is even	electron and proton is even
Which of the following is not correct for sh	Spin-orbit coupling determini	Each nucleon in nucleus moves	Pauli exclusion principle is a	As a spherical nucleus is a ce	As a spherical nucleus is a central field, existence of average field is not necessary
In the nuclear shell model, the spin of the g	is decided by the last unpaired	is always zero	is always integral	is decided by the core	is decided by the last unpaired nucleus
A condition for nuclear isomerism	The presence of an energy lev	The presence of an energy level	The presence of states differi	The existence of mirror nucle	The presence of an energy level near the ground state differing strongly in angular momentum
In nuclear shell model, orbitals are filled in	Binding energy	Emission of β,α-particles	Mirror nucleus	Spin-orbit coupling of nucleo	Spin-orbit coupling of nucleons
The expected shell model spin and parity a	$5/2^+$	$1/2^+$	$3/2^-$	$½^-$	$5/2^+$
The expected shell model spin and parity a	$3/2^-$	$3/2^+$	$5/2^+$	$5/2^-$	$3/2^-$

The expected shell model spin and parity as	$1/2^+$	$5/2^-$	$3/2^+$	$3/2^-$	$1/2^+$
The expected shell model spin and parity as	$3/2^+$	$5/2^+$	$1/2^+$	$½^-$	$5/2^+$
Nuclear shell model is proposed by	Faraday	Bohr	M.G.Mayer	None of these	M.G.Mayer
Nuclear shell model is based on the realizat	quantum number	magic number	bonding energy	critical number	Magic number
There is a critical energy called …………w	Activation energy	Thermal energy	Nuclear energy	none of these	Activation energy
Seaborg's expression is given by	E_f=19.0-0.36Z^2/A	E_f =19.0-0.36Z^3/A	E_f =19.0-0.36Z/A	None of these	E_f =19.0-0.36Z^2/A
The first theoretical treatment of the fission	Yukawa	Bohr	Bohr and Wheeler	None of these	Bohr and Wheeler
Property associated with the shape and is a	Magnetic dipole moment	Electric quadrupole moment	Angular momentum	None of these	Electric quadrupole moment
The nucleus may have quadrupole moment	≥2	≥1	≤1	Zero	≥2
Which of the following reactions involves r	disintegration	radiative capture	direct reactions	elastic scattering	elastic scattering
For any spherical symmetric distribution of l		>1	<1	Zero	zero
In spallation reactions, heavy nuclei splits i	two nuclei	one nuclei	no change	more than four nuclei	two nuclei
Direct reactions include	pickup reactions	stripping reaction	1 & 2	spontaneous decay	1 & 2
Bohr and Wheeler theory is explained base	Shell model	Unified model	nilsson model	Liquid drop model	Liquid drop model

Prepared by Dr. B. Janarthanan, Associate Professor, Department of Physics, KAHE

UNIT-IV

SYLLABUS

Nuclear reactions: Nuclear fission and fusion - Kinds of reaction and conservation laws - energetics of nuclear reaction – Applications of Nuclear Energy – Nuclear Reactors - Isospin - Reaction cross section-Continuum theory of nuclear reaction - Resonance - Briet Wigner Dispersion formula - Stages of nuclear reaction - Statistical theory of nuclear reaction - Evaporation probability and cross section – Kinematics of stopping and pickup reaction - Surface reaction

Nuclear fission and fusion:

Nuclear fission is the splitting of a heavy nucleus into two lighter ones. Fission was discovered in 1938 by the German scientists Otto Hahn, Lise Meitner, and Fritz Strassmann, who bombarded a sample of uranium with neutrons in an attempt to produce new elements with Z > 92. They observed that lighter elements such as barium (Z = 56) were formed during the reaction, and they realized that such products had to originate from the neutron-induced fission of uranium-235.

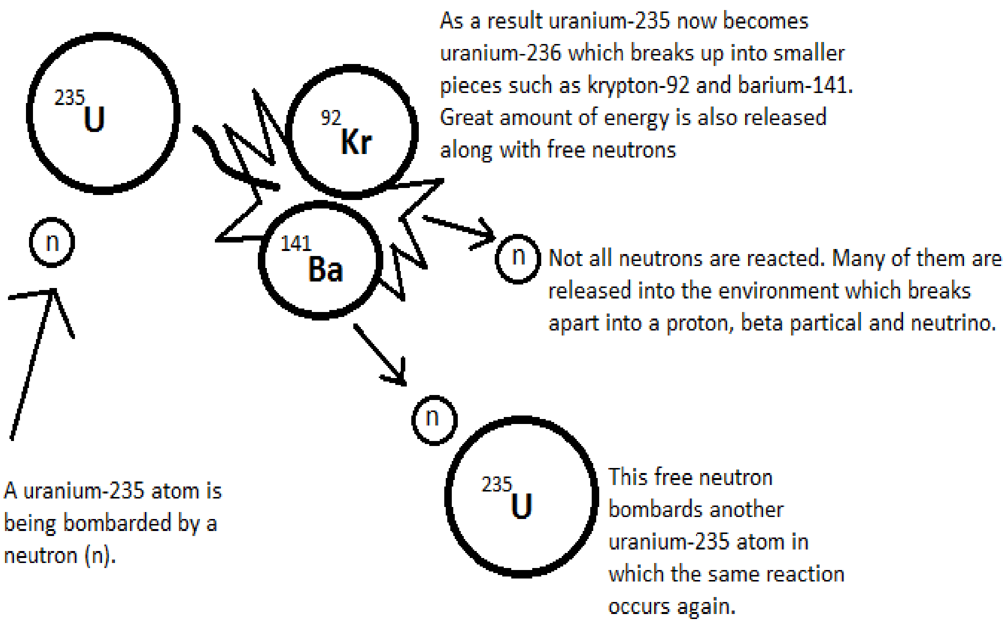
This hypothesis was confirmed by detecting the krypton-92 fission product. As discussed in Section 20.2, the nucleus usually divides asymmetrically rather than into two equal parts, and the fission of a given nuclide does not give the same products every time.

In a typical nuclear fission reaction, more than one neutron is released by each dividing nucleus. When these neutrons collide with and induce fission in other neighboring nuclei, a self-sustaining series of nuclear fission reactions known as a **nuclear chain reaction** can result. For example, the fission of ^{235}U releases two to three neutrons per fission event. If absorbed by other ^{235}U nuclei, those neutrons induce additional fission events, and the rate of the fission reaction increases geometrically. Each series of events is called a generation. Experimentally, it is found that some minimum mass of a fissile isotope is required to sustain a nuclear chain reaction; if the mass is too low, too many neutrons are able to escape without being captured and inducing a fission reaction. The minimum mass capable of supporting sustained fission is called the **critical mass**. This amount depends on the purity of the material and the shape of the mass, which corresponds to the amount of surface area available from which neutrons can escape, and on the identity of the isotope. If the mass of the fissile isotope is greater than the critical mass, then under the right conditions, the resulting supercritical mass can release energy explosively. The enormous energy released from nuclear chain reactions is responsible for the massive destruction caused by the detonation of nuclear weapons such as fission bombs, but it also forms the basis of the nuclear power industry.

Nuclear fusion, in which two light nuclei combine to produce a heavier, more stable nucleus, is the opposite of nuclear fission. As in the nuclear transmutation reactions discussed in Section 20.2, the positive charge on both nuclei results in a large electrostatic energy barrier to fusion. This barrier can be overcome if one or both particles have sufficient kinetic energy to overcome the electrostatic repulsions, allowing the two nuclei to approach close enough for a fusion reaction to occur. The principle is similar to adding heat to increase the rate of a chemical reaction. For example, in a typical fusion reaction, two deuterium atoms combine to produce helium-3, a process known as deuterium–deuterium fusion (D–D fusion).

Fission

Fission is the splitting of a nucleus that releases free neutrons and lighter nuclei. The fission of heavy elements is highly exothermic which releases about 200 million eV compared to burning coal which only gives a few eV. The amount of energy released during nuclear fission is millions of times more efficient per mass than that of coal considering only 0.1 percent of the original nuclei is converted to energy. Daughter nucleus, energy, and particles such as neutrons are released as a result of the reaction. The particles released can then react with other radioactive materials which in turn will release daughter nucleus and more particles as a result, and so on. The unique feature of nuclear fission reactions is that they can be harnessed and used in chain reactions. This chain reaction is the basis of nuclear weapons. One of the well known elements used in nuclear fission is U_{235}, which when is bombarded with a neutron, the atom turns into U_{236} which is even more unstable and splits into daughter nuclei such as Krypton-92 and Barium-141 and free neutrons. The resulting fission products are highly radioactive, commonly undergoing $\beta-\beta-$ decay.



Nuclear fission is the splitting of the nucleus of an atom into nuclei of lighter atoms, accompanied by the release of energy, brought on by a neutron bombardment. The original concept of this nuclei splitting was discovered by Enrico Femi in 1934—who believed transuranium elements might be produced by bombarding uranium with neutrons, because the loss of Beta particles would increase the atomic number. However, the products that formed did not correlate with the properties of elements with higher atomic numbers than uranium (Ra, Ac, Th, and Pa). Instead, they were radioisotopes of much lighter elements such as Sr and Ba. The amount of mass lost in the fission process is equivalent to an energy of $3.20\times10^{-11}J$3.20×10−11J.

Critical Mass

The explosion of a bomb only occurs if the chain reaction exceeds its critical mass. The critical mass is the point at which a chain reaction becomes self-sustaining. If the neutrons are lost at a faster rate than they are formed by fission, the reaction will not be self-sustaining. The spontaneous nuclear fission rate is the probability per second that a given atom will fission spontaneously--that is, without any external intervention. In nuclear power plants, nuclear fission is controlled by a medium such as water in the nuclear reactor. The water acts as a heat transfer medium to cool down the reactor and to slow down neutron particles. This way, the neutron emission and usage is a controlled. If nuclear reaction is not controlled because of lack of cooling water for example, then a meltdown will occur.

Fusion

Nuclear fusion is the joining of two nuclei to form a heavier nuclei. The reaction is followed either by a release or absorption of energy. Fusion of nuclei with lower mass than iron releases energy while fusion of nuclei heavier than iron generally absorbs energy. This phenomenon is known as **iron peak**. The opposite occurs with nuclear fission.

The power of the energy in a fusion reaction is what drives the energy that is released from the sun and a lot of stars in the universe. Nuclear fusion is also applied in nuclear weapons, specifically, a hydrogen bomb. Nuclear fusion is the energy supplying process that occurs at extremely high temperatures like in stars such as the sun, where smaller nuclei are joined to make a larger nucleus, a process that gives off great amounts of heat and radiation. When uncontrolled, this process can provide almost unlimited sources of energy and an uncontrolled chain provides the basis for a hydrogen bond, since most commonly hydrogen is fused. Also, the combination of deuterium atoms to form helium atoms fuel this thermonuclear process.:

However, a controlled fusion reaction has yet to be fully demonstrated due to many problems that present themselves including the difficulty of forcing deuterium and tritium nuclei within a close proximity, achieving high enough thermal energies, and completely ionizing gases into plasma. A necessary part in nuclear fusion is **plasma**, which is a mixture of atomic nuclei and electrons that are required to initiate a self-sustaining reaction which requires a temperature of more than 40,000,000 K. Why does it take so much heat to achieve nuclear fusion even for light elements such as hydrogen? The reason is because the nucleus contain protons, and in order to overcome electrostatic repulsion by the protons of both the hydrogen atoms, both of the hydrogen nucleus needs to accelerate at a super high speed and get close enough in order for the nuclear force to start fusion. The result of nuclear fusion releases more energy than it takes to start the fusion so ΔG of the system is negative which means that the reaction is exothermic. And because it is exothermic, the fusion of light elements is self-sustaining given that there is enough
energy to start fusion in the first place.

Kinds of reactions:

1. Elastic scattering

In this case, the incident particle strikes the target nucleus and leaves without losing energy ,but its direction may change .

for eg ; scattering αα -particle from the thin foil of gold .

2. Inelastic collision

In this type of nuclear reaction ,the kinetic energy is not conserved but a part of the energy of the incident particle is taken up by the target nucleus which is excited to a higher quantum state and then later it decays to the ground state radiating the excess energy in the form of γγ photon. Example: **Nuclear reaction and fission.**

3.Simple or radiative capture

In this case ,the incident particles is captured by the target nucleus and a new nucleus is formed .The new nucleus ,in general, has a considerable excess energy and decay with the emission of one or more γγ - rays photons ,

4.Disintegration

This is the most general type of nuclear reaction where the incident particle will absorb and a different particle is ejected .

(a), protons

When the bombarding particles is a proton ,it ma give rise to (p ,αα) ,(p ,D) or a (p, n) reaction . Reaction of the type(p ,αα) and (p ,D) are less common and (p,n) are more likely .

(b) Deutrons

Accelerated neutrons give rise to a number of nuclear reaction .

(c) , αα-particles

In this case the αα particles is generally absorbed by the light nuclei by the process of resonance capture it the emission of a γγ ray photon reaction of (αα,p) and (αα ,n) may be form some times .

(d), Neutrons,

The interaction of neutrons with nuclei may result in (n γγ), (nαα) (n,p) (n,n) and (n,2n) reaction respectively .

5 .Photo disintegration

The nuclear reaction brought out by high energy radiation (i.e γγ-rays) then is known as photodisintegration to produce Photodisintegration ,the energy of the incident photon must be greater than the binding energy of particle to be ejected .

If the energy is not sufficient even to remove a neutron, the nucleus may enter one of the its excited states and later emit excess energy as radiation ,

6. Stripping and pick-up reaction

In this type of the reaction, one or more nucleons from the projectile are captured by the target while the remainder continuous on its way ,

When deuteron is accelerated to a high energy and then subjected to a magnetic field the proton gets deflected while the neutron continuous to pass straight.

In pick up reaction an incident particle collides with target nucleus and immediately pulls out one of the nucleons from the target nucleus. This happens when the de-Broglie wavelength associated with the incident particle is almost equal to the average distance between the nucleons so that interaction can be restricted to one nucleon. The stripping and pick up reaction don't proceed through the formation of compound nucleons as the intermediate stage.

7. Fission and spallation reactions

In a fission reaction, the target nucleus after interacting with the projectile splits mainly into two lighter nuclei of comparable mass and the same time it emits a few neutrons.

When the projectile has sufficiently large energy the target nucleus split into twenty or thirty nucleons and some alpha particles leaving behind a number of nuclei of significantly smaller mass. This is known as spallation

8.Heavy ion and high energy reaction

When the incident particle is heavier than alpha particle the reaction is known as a heavy iron reaction. This type of reaction was observed in 1950 at Berkley with accelerated carbon ion and the aluminium target.

This type of reaction has properties of both compound nucleus and of stripping and pick up mechanism

9. Fusion

In a fusion reaction lighter elements combine to give a new element along with release large amount of energy.

Conservation laws:

1.Conservation of charge:

In nuclear reaction the total charge before and after the reaction is conserved ,In other words ,the sum of charge on the reactants side is equal to the sum of the charge the product sides .

2, Conservation of mass number:

In nuclear reaction the total mass number or total number of nucleons before reaction and after the reaction remains same, this is because the nucleons neither be created or destroyed ,

3, Conservation of mass-energy:

In any nuclear reaction neither K.E. nor rest mass energy conserved separately, but their total energy is always conserved.

4,Conservation of linear momentum:

In nuclear reaction the total linear momentum of the particle taking part in a nuclear reaction must be the same before and after the reaction , If v_a ,v_b and V_y are the velocities of the incident particles, the emitted particles and the product of nucleus respectively ,then their linear momentum is $m_a v_a$,$m_b v_b M_y V_y$ must be capable of representation by the sides of the triangle taken in order because their vector sum must be zero .

5 .Conservation of angular momentum :

The angular momentum I→I→ is composed of intrinsic spin angular momentum s→s→ and relative orbital angular momentumI→I→ In any nuclear reaction ,the vector sum of the total angular momenta of the atoms must be conserved before and after of the reaction .

6, Conservation of spin and statistics:

In nuclear reaction, the spin and statistical character must remain the same before and after the nuclear reaction . Thus the statistics followed by the product must be the same as that followed by the reactants ; either Fermi-Dirac (for even A) or Bose-Einstein (for odd A)

7,Conservation of parity:

The total parity of the system is the product of the intrinsic parities of the target nucleus and the bombarding (nucleus) particle .The net parity before and after the reaction must be equal ,

NoViolation of parity has been observed in a nuclear reaction for strong nuclear force ,However ,parity does not appear to be conserved in weak interactions .

8.Conservation of nucleons:The total number of nucleons before and after a reaction are the same.

Energetics of nuclear reactions:

Nuclear reactions, like chemical reactions, are accompanied by changes in energy. The energy changes in nuclear reactions, however, are enormous compared with those of even the most energetic chemical reactions. In fact, the energy changes in a typical nuclear reaction are so large that they result in a measurable change of mass. In this section, we describe the relationship between mass and energy in nuclear reactions and show how the seemingly small changes in mass that accompany nuclear reactions result in the release of enormous amounts of energy.

Mass–Energy Balance

The relationship between mass (m) and energy (E) is expressed in the following equation:

$E=mc^2$

where

- cc is the speed of light (2.998×108m/s2.998×108m/s), and
- EE and mm are expressed in units of joules and kilograms, respectively.

Albert Einstein first derived this relationship in 1905 as part of his special theory of relativity: the mass of a particle is directly proportional to its energy. Thus according to Equation every mass has an associated energy, and similarly, any reaction that involves a change in energy must be accompanied by a change in mass. This implies that all exothermic reactions should be accompanied by a decrease in mass, and all endothermic reactions should be accompanied by an increase in mass.

Combustion reactions are typically carried out at constant pressure, and under these conditions, the heat released or absorbed is equal to ΔH. When a reaction is carried out at constant volume, the heat released or absorbed is equal to ΔE. For most chemical reactions, however, ΔE ≈ ΔH. If we rewrite Einstein's equation as

$\Delta E=(\Delta m)c^2$

we can rearrange the equation to obtain the following relationship between the change in mass and the change in energy:

$\Delta m=\Delta E c^2$

Nuclear Binding Energies

We have seen that energy changes in both chemical and nuclear reactions are accompanied by changes in mass. Einstein's equation, which allows us to interconvert mass and energy, has another interesting consequence: The mass of an atom is always less than the sum of the masses of its component particles. The only exception to this rule is hydrogen-1 (^1H), whose measured mass of 1.007825 amu is identical to the sum of the masses of a proton and an electron. In contrast, the experimentally measured mass of an atom of deuterium (^2H) is 2.014102 amu, although its calculated mass is 2.016490 amu:

m2H=$m_{neutron}$+m_{proton}+$m_{electron}$=1.008665 amu+1.007276 amu+0.000549 amu=2.016490 amu.

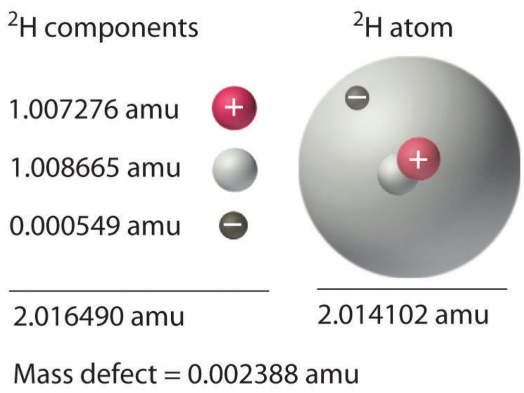
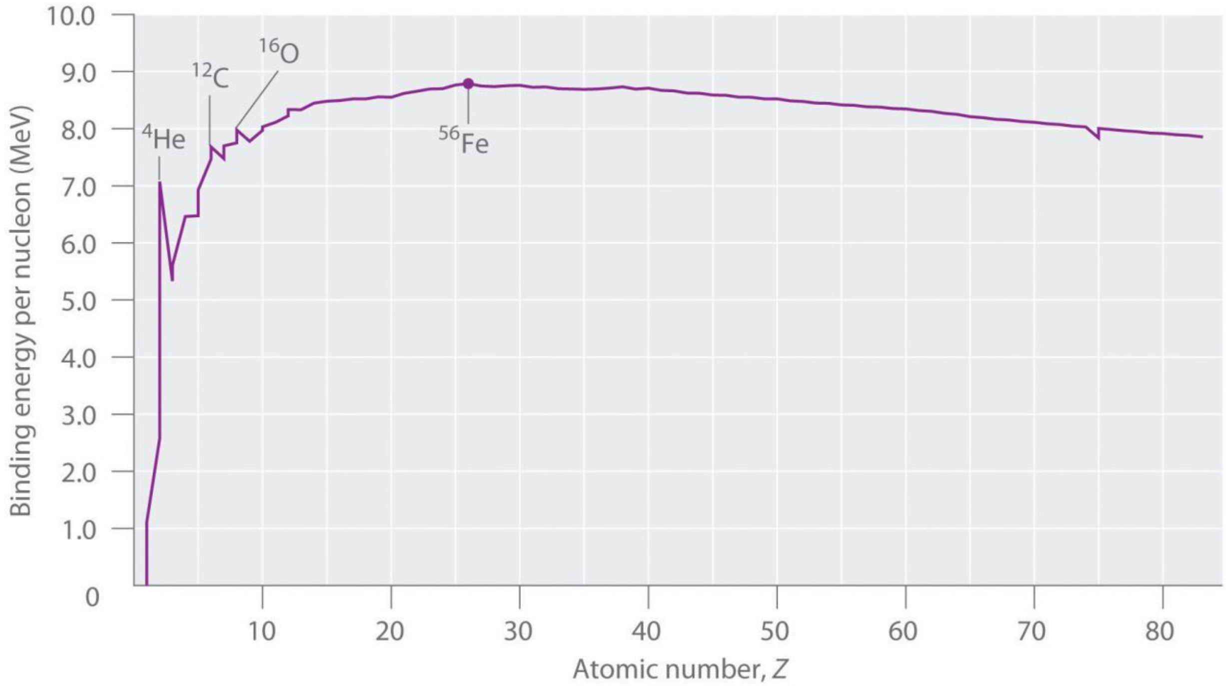


Figure 25.6.125.6.1**:** Nuclear Binding Energy in Deuterium. The mass of a ^{2}H atom is less than the sum of the masses of a proton, a neutron, and an electron by 0.002388 amu; the difference in mass corresponds to the nuclear binding energy. The larger the value of the mass defect, the greater the nuclear binding energy and the more stable the nucleus.

The amount of energy released when a nucleus forms from its component nucleons is the **nuclear binding energy** (Figure 25.6.125.6.1). In the case of deuterium, the mass defect is 0.002388 amu, which corresponds to a nuclear binding energy of 2.22 MeV for the deuterium nucleus. Because the magnitude of the mass defect is proportional to the nuclear binding energy, both values indicate the stability of the nucleus.

Not all nuclei are equally stable. Chemists describe the relative stability of different nuclei by comparing the binding energy per nucleon, which is obtained by dividing the nuclear binding energy by the mass number (A) of the nucleus. As shown in Figure 25.6.225.6.2, the binding energy per nucleon increases rapidly with increasing atomic number until about Z = 26, where it levels off to about 8–9 MeV per nucleon and then decreases slowly. The initial increase in binding energy is not a smooth curve but exhibits sharp peaks corresponding to the light nuclei that have equal numbers of protons and neutrons (e.g., ^{4}He, ^{12}C, and ^{16}O). As mentioned earlier, these are particularly stable combinations.

Figure 25.6.22



5.6.2: The Curve of Nuclear Binding Energy. This plot of the average binding energy per nucleon as a function of atomic number shows that the binding energy per nucleon increases with increasing atomic number until about Z = 26, levels off, and then decreases. The sharp peaks correspond to light nuclei that have equal numbers of protons and neutrons.

Because the maximum binding energy per nucleon is reached at ^{56}Fe, all other nuclei are thermodynamically unstable with regard to the formation of ^{56}Fe. Consequently, heavier nuclei (toward the right in Figure 25.6.225.6.2) should spontaneously undergo reactions such as alpha decay, which result in a decrease in atomic number. Conversely, lighter elements (on the left in Figure 25.6.225.6.2) should spontaneously undergo reactions that result in an increase in atomic number. This is indeed the observed pattern.

Applications of nuclear energy:

The main use of nuclear energy is the production of electric energy. Nuclear power plants are responsible for generating electricity. Nuclear fission reactors are generated in the nuclear reactors of the nuclear power plants. With these reactions thermal energy is obtained which will be transformed into mechanical energy and later into electrical energy.

However, there are many other applications where nuclear technology is used directly or indirectly.

Working with different isotopes of the same element, nuclear technology can be used for other applications in various fields:

Industrial applications of nuclear energy:

Nuclear technology is of great importance in the industrial sector, specifically used in the development and improvement of processes, for measurements, automation and quality control.

Used as a prerequisite for the complete automation of high-speed production lines, and applies to process research, mixing, maintenance and study of wear and corrosion of plant and machinery.

Nuclear technology is also used in the manufacture of plastics and in the sterilization of disposable products.

Military applications, nuclear weapons:

A weapon is an instrument used to attack or defend itself. Nuclear weapons are those weapons that use nuclear technology. Depending on the role of nuclear technology in the weapon, two types of nuclear weapons differ: those that use nuclear energy to exploit, such as the atomic bomb, and those that use nuclear technology to propel. This second category includes cruises, aircraft carriers, submarines …

Nuclear medicine:

One in three patients who go to a hospital in an industrialized country receive the benefits of some kind of nuclear medicine procedure. Radiopharmaceuticals are used, such as radiotherapy for the treatment of malignant tumors, teletherapy for oncological treatment or radiological biology that allows the sterilization of medical products.

Applications in agriculture of nuclear energy:

The application of isotopes to agriculture has made it possible to increase agricultural production in the least developed countries.

Nuclear technology is very useful in controlling insect pests, maximizing water resources, improving crop varieties or establishing the conditions necessary to optimize the efficiency of fertilizers and Water.

Application of nuclear technology to food

As for food, nuclear techniques play a key role in food preservation.
The application of isotopes allows a significant increase in the conservation of food. At present, more than 35 countries allow the irradiation of some foods.

Environmental applications of nuclear technology

The application of isotopes makes it possible to determine the exact quantities of pollutants and places where they are present and their causes. In addition, electron beam treatment reduces the environmental and health consequences of large-scale use of fossil fuels, and contributes more effectively than other techniques to solving problems such as "the greenhouse effect" And acid rain.

Other applications of nuclear technology

Like dating, which uses the properties of carbon-14 fixation to bones, woods or organic waste, determining their chronological age, and the uses in Geophysics and Geochemistry, that take advantage of the existence of natural radioactive materials for the fixation of the Dates of deposits of rocks, coal or oil.
Other applications of nuclear technology occur in disciplines such as hydrology, mining or space industry.

Nuclear reactors:

A nuclear reactor is a system that contains and controls sustained nuclear chain reactions. Reactors are used for generating electricity, moving aircraft carriers and submarines, producing medical isotopes for imaging and cancer treatment, and for conducting research.
Fuel, made up of heavy atoms that split when they absorb neutrons, is placed into the reactor vessel (basically a large tank) along with a small neutron source. The neutrons start a chain reaction where each atom that splits releases more neutrons that cause other atoms to split. Each time an atom splits, it releases large amounts of energy in the form of heat. The heat is carried out of the reactor

by coolant, which is most commonly just plain water. The coolant heats up and goes off to a turbine to spin a generator or drive shaft. **Nuclear reactors are just exotic heat sources.**

Main components

- **The core** of the reactor contains all of the nuclear fuel and generates all of the heat. It contains low-enriched uranium (<5% U-235), control systems, and structural materials. The core can contain hundreds of thousands of individual fuel pins.
- **The coolant** is the material that passes through the core, transferring the heat from the fuel to a turbine. It could be water, heavy-water, liquid sodium, helium, or something else. In the US fleet of power reactors, water is the standard.
- **The turbine** transfers the heat from the coolant to electricity, just like in a fossil-fuel plant.
- **The containment** is the structure that separates the reactor from the environment. These are usually dome-shaped, made of high-density, steel-reinforced concrete. Chernobyl did not have a containment to speak of.
- **Cooling towers** are needed by some plants to dump the excess heat that cannot be converted to energy due to the laws of thermodynamics. These are the hyperbolic icons of nuclear energy. They emit only clean water vapor.

Types of Reactors

There are many different kinds of nuclear fuel forms and cooling materials can be used in a nuclear reactor. As a result, there are thousands of different possible nuclear reactor designs. Here, we discuss a few of the designs that have been built before, but don't limit your imagination; many other reactor designs are possible. Dream up your own!

Pressurized Water Reactor

The most common type of reactor. The PWR uses regular old water as a coolant. The primary cooling water is kept at very high pressure so it does not boil. It goes through a heat exchanger, transferring heat to a secondary coolant loop, which then spins the turbine. These use oxide fuel pellets stacked in zirconium tubes. They could possibly burn thorium or plutonium fuel as well.

Pros:

- Strong negative void coefficient — reactor cools down if water starts bubbling because the coolant is the moderator, which is required to sustain the chain reaction

- Secondary loop keeps radioactive stuff away from turbines, making maintenance easy.
- Very much operating experience has been accumulated and the designs and procedures have been largely optimized.
- Pressurized coolant escapes rapidly if a pipe breaks, necessitating lots of back-up cooling systems.
- Can't breed new fuel — susceptible to "uranium shortage"

Boiling Water Reactor

Second most common, the BWR is similar to the PWR in many ways. However, they only have one coolant loop. The hot nuclear fuel boils water as it goes out the top of the reactor, where the steam heads over to the turbine to spin it.

Pros:

- Simpler plumbing reduces costs
- Power levels can be increased simply by speeding up the jet pumps, giving less boiled water and more moderation. Thus, load-following is simple and easy.
- Very much operating experience has been accumulated and the designs and procedures have been largely optimized.
- With liquid and gaseous water in the system, many weird transients are possible, making safety analysis difficult
- Primary coolant is in direct contact with turbines, so if a fuel rod had a leak, radioactive material could be placed on the turbine. This complicates maintenance as the staff must be dressed for radioactive environments.
- Can't breed new fuel — susceptible to "uranium shortage"
- Does not typically perform well in station blackout events, as in Fukushima.

Canada Deuterium-Uranium Reactors (CANDU)

CANDUs are a Canadian design found in Canada and around the world. They contain heavy water, where the Hydrogen in H2O has an extra neutron (making it Deuterium instead of Hydrogen). Deuterium absorbs many fewer neutrons than Hydrogen, and CANDUs can operate using only natural uranium instead of enriched.

Pros:

- Require very little uranium enrichment.

- Can be refueled while operating, keeping capacity factors high (as long as the fuel handling machines don't break).
- Are very flexible, and can use any type of fuel.
- Some variants have positive coolant temperature coefficients, leading to safety concerns.
- Neutron absorption in deuterium leads to tritium production, which is radioactive and often leaks in small quantities.
- Can theoretically be modified to produce weapons-grade plutonium slightly faster than conventional reactors could be.

Sodium Cooled Fast Reactor

These reactors are cooled by liquid sodium metal. Sodium is heavier than hydrogen, a fact that leads to the neutrons moving around at higher speeds (hence fast). These can use metal or oxide fuel, and burn a wide variety of fuels.

Pros:

- Can breed its own fuel, effectively eliminating any concerns about uranium shortages (see what is a fast reactor?)
- Can burn its own waste
- Metallic fuel and excellent thermal properties of sodium allow for passively safe operation — the reactor will shut itself down safely without any backup-systems working (or people around), only relying on physics.
- Sodium coolant is reactive with air and water. Thus, leaks in the pipes results in sodium fires. These can be engineered around but are a major setback for these reactors.
- To fully burn waste, these require reprocessing facilities which can also be used for nuclear proliferation.
- The excess neutrons used to give the reactor its resource-utilization capabilities could clandestinely be used to make plutonium for weapons.
- Positive void coefficients are inherent to most fast reactors, especially large ones. This is a safety concern.
- Not as much operating experience has been accumulated. We have only about 300 reactor-years of experience with sodium cooled reactors

Molten Salt Reactor

Molten Salt Reactor's (MSRs) are the internet's favorite reactor. They are unique so far in that they use fluid fuel.

Pros:

- Can constantly breed new fuel, eliminating concerns over energy resources
- Can make excellent use of thorium, an alternative nuclear fuel to uranium
- Can be maintained online with chemical fission product removal, eliminating the need to shut down during refueling.
- No cladding means less neutron-absorbing material in the core, which leads to better neutron efficiency and thus higher fuel utilization
- Liquid fuel also means that structural dose does not limit the life of the fuel, allowing the reactor to extract very much energy out of the loaded fuel.
- Radioactive gaseous fission products are not contained in small pins, as they are in typical reactors. So if there is a containment breach, all the fission gases can release instead of just the gases from one tiny pin. This necessitates things like triple-redundant containments, etc. and can be handled.
- The presence of an online reprocessing facility with incoming pre-melted fuel is a proliferation concern. The operator could divert Pa-233 to provide a small stream of nearly pure weapons-grade U-233. Also, the entire uranium inventory can be separated without much effort. In his autobiography, Alvin Weinberg explains how this was done at Oak Ridge National Lab: "It was a remarkable feat! In only 4 days all of the 218 kg of uranium in the reactor were separated from the intensely radioactive fission products and its radioactivity reduced five billion-fold."
- Very little operating experience, though a successful test reactor was operated in the 1960s

High Temperature Gas Cooled Reactor

HTGRs use little pellets of fuel backed into either hexagonal compacts or into larger pebbles (in the prismatic and pebble-bed designs). Gas such as helium or carbon dioxide is passed through the reactor rapidly to cool it. Due to their low power density, these reactors are seen as promising for using nuclear energy outside of electricity: in transportation, in industry, and in residential regimes. They are not particularly good at just producing electricity.

- Can operate at very high temperatures, leading to great thermal efficiency (near 50%!) and the ability to create process heat for things like oil refineries, water desalination plants, hydrogen fuel cell production, and much more.
- Each little pebble of fuel has its own containment structure, adding yet another barrier between radioactive material and the environment.
- High temperature has a bad side too. Materials that can stay structurally sound in high temperatures and with many neutrons flying through them are hard to come by.
- If the gas stops flowing, the reactor heats up very quickly. Backup cooling systems are necessary.
- Gas is a poor coolant, necessitating large amounts of coolant for relatively small amounts of power. Therefore, these reactors must be very large to produce power at the rate of other reactors.
- Not as much operating experience

Isospin:

In particle physics and nuclear physics, isospin, **I** or $\mathbf{I_3}$, is a **quantum number** related to the **strong nuclear force**. Isospin is associated with a conservation law which requires strong interaction decays to conserve isospin. This term was derived from isotopic spin, but physicists prefer the term isobaric spin, which is more precise in meaning.

Isospin was introduced by a German theoretical physicist and one of the key pioneers of quantum mechanics **Werner Karl Heisenberg** in 1932 as a way of **distinguishing** between **protons** and **neutrons**. It must be added, the concept of isospin was introduced before the development of the quark model, in the 1960s, which provides our modern understanding.

The observations have showed that the strong interaction does not distinguish between these nucleon. The strength of the **strong interaction** between any pair of nucleons is the same, **independent** of whether they are interacting as neutrons or as protons. Instead of regarding protons and neutrons as totally different species, as far as strong interactions are concerned, they are regarded as being **different isospin states of the same underlying nucleon particle**. This particle is called the **nucleon.** Similarly, the three pions, π^0, π^+ and π^-, seem to be only **three different states** of the same particle, when only a strong nuclear force interacts. Isospin is mathematically similar to spin, though it has nothing to do with angular momentum. The spin term is tacked on because the addition of the isospins follows the same rules as spin.

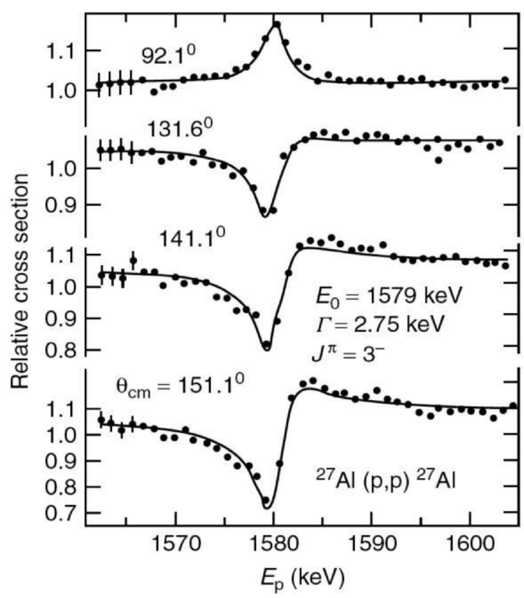
The proton has isotopic spin ½ as the neutron has isotopic spin ½, but in case of proton the spin is pointing upwards and the spin of neutron is pointing downwards.

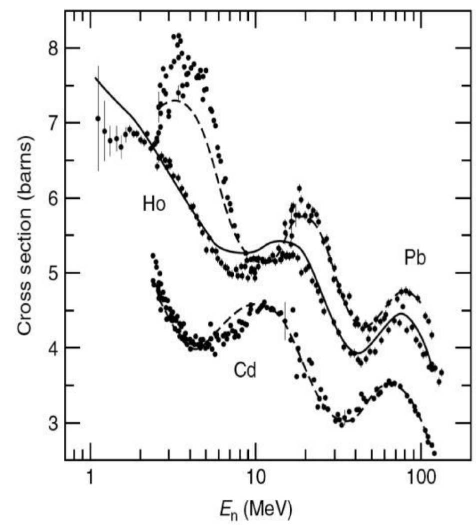
In general, each **multiplet** is assigned a isospin number I that is a positive integer or half an odd positive integer. Isospin may be considered to be a vector not in coordinate space (x, y, z). The third component, T_3, may take on any one of the values T, T − 1, T − 2, . . ., −T in a fashion similar to the values of the z component of angular momentum. Two other components, T_1 and T_2 can be ignored. Each of T_3 values corresponds to a different member of the multiplet. There are 2T + 1 particles in the multiplet. This result follows from counting the possible values of T_3. Thus singlets have T = 0, doublets have T = 1/2, and triplets have T = 1.

Total isospin for a collection of particles is computed in the same manner as for ordinary spin. , The maximum value of system isospin is the sum of the individual particle's isospins. For example if one considers π^+ - p scattering, $T_{max} = 3/2$ and $T_3 = 3/2$ so T can only have the value 3/2. For π^- − p scattering, $T_{max} = 3/2$ and $T_3 = -1/2$ so T can be either 3/2 or 1/2. In fact, measurement of T for π − -p sometimes produces T = 3/2 and sometimes T = 1/2 but always $T_3 = -1/2$.

Statistical theory of nuclear reactions:

The actuating behavior of low-energy nuclear reactions is due to the interference of the reaction amplitude corresponding to the excitation of each of the overlap-ping states which vanish in the energy average of the cross-section since these amplitudes are complex functions with random modulus and phase. Calling $_N$ (c) the cross section for the formation of a compound nucleus in the entrance channel c, and using the reciprocity theorem which relates the cross-section $_{cc}0$ to the cross-section for the time-reversed process.





Ejectiles with energy in the range E_c0 to E_c0 + dE_c0 leave the residual nucleus with energy in the range U_c0 to U_c0 + dU_c0 where U_c0 = E_{CN} B_c0 E_c0 and E_{CN} and B_c0 are respectively the compound nucleus energy and the binding energy of the ejectile in the com-pound nucleus. Eq. 44 is the Weisskopf-Ewing formula for the angle-integrated cross-sections [11]. To a good approximation, the level density !(U) / exp(U=T), so the ejectile spectrum given by the Weisskopf-Ewing theory is Maxwellian. It rises rapidly above the threshold energy, attains a maximum and then falls exponentially. _

takes into account the formation of the compound nucleus in states of different J and parity . Let us consider the case of a reaction leading from the initial channel c to a nal channel . If there is no pre-equilibrium emission, one may identify the compound nucleus formation cross-section with the optical model reaction cross-section; which, if the transmission coeffcients do not depend on J. hS_li is the average value of the scattering amplitude over several overlapping resonances.

The compound nucleus states may be both of positive and negative parity. Since parity is conserved, in evaluating (45), one must take into account that the parity of compound nucleus states and the parity of the residual nucleus states may impose restrictions to the values of the emitted particle angular momentum. Thus, positive parity compound nucleus states decay to positive parity states of the residual only by even angular momenta and to negative parity residual nucleus states by odd angular momenta.

Reaction Cross section

As nuclear reaction is a statistical phenomenon, it is required to define some physical quantity to determine the probability of a nuclear reaction. The quantity which gives the idea of the probability of any physical process (e.g. nuclear reaction) to occur is known as cross-section. Nuclear reaction cross section can be defined in the following manner: σ = Number of given types of events per unit time per nucleus/number of projectile particles per unit area, unit time. Considering two broad physical process i.e. scattering and absorption, the total cross section σ_{tot} is written as:

$\sigma_{tot} = \sigma_{sc} + \sigma_a$

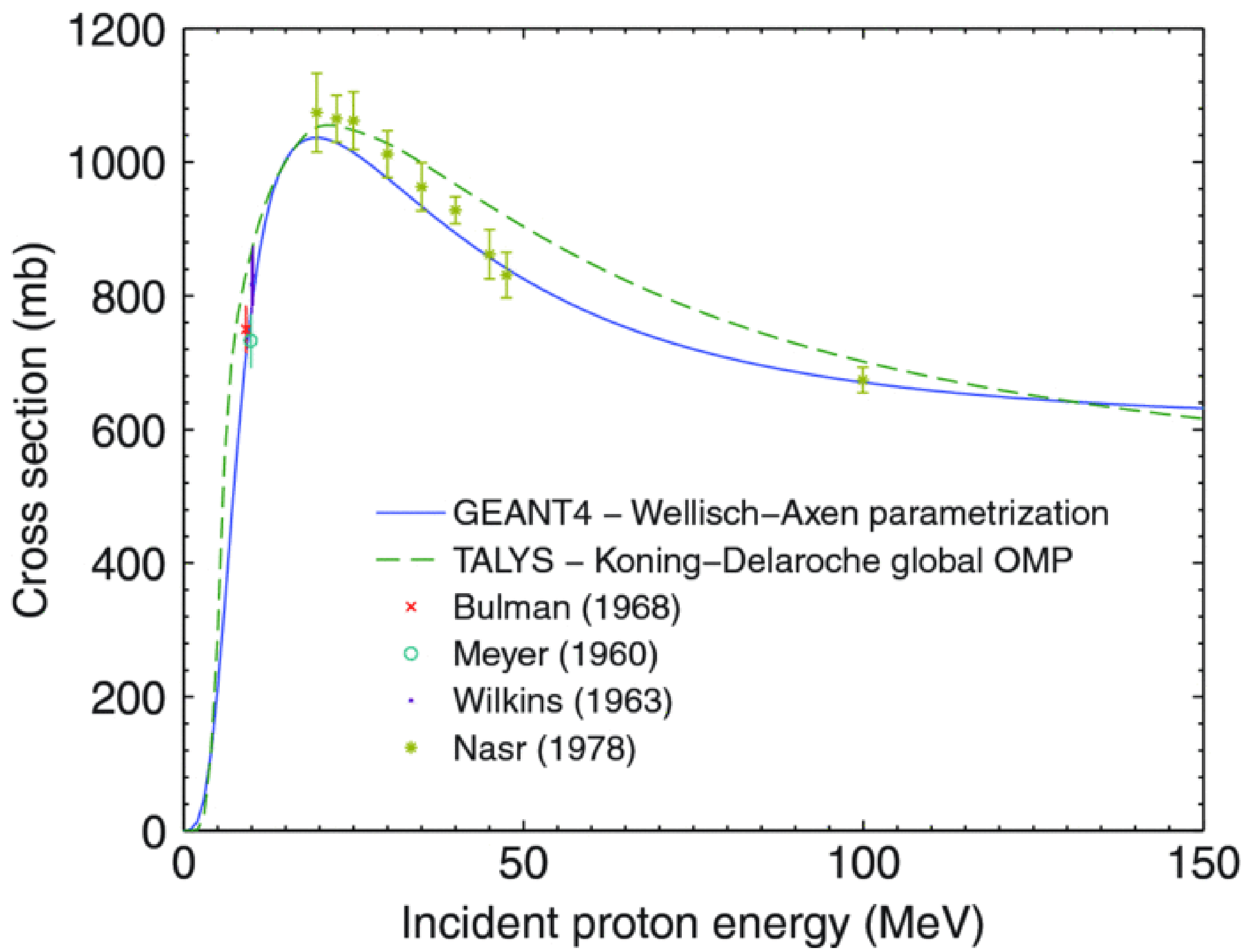
where

σ_{sc} =scatteringcross-section

σ_a =absorptioncross-section

The unit of cross-section is 'barn' having the dimension of area (1 barn = 10^{-24} cm^2 = 10^{-28}m^2).

A nuclear reaction is symbolized by a parenthesis containing the projectile and product particle symbolically. At the beginning of the parenthesis, the symbol of target nucleus, and after the parenthesis, the symbol of the product nucleus is written. To represent a particular reaction, say, a deuteron irradiating $^{14}_{7}N$ to produce $^{15}_{7}N$ and a proton, the symbol is $^{14}_{7}N(d,p)^{15}_{7}N$. Depending on the projectile and the product particle, a large number of nuclear reactions are possible.



Continuum theory of nuclear reaction:

At higher bombarding energies the individual levels of the compound nucleus become broader and also more closely spaced. The total width Γ becomes much greater than D, the spacing of the levels. The width and number of levels may be found in it. Sharp resonances are no longer observable when Γ>D. the spacing between levels is completely occupied, so the space is described as continuum. The cross-section for the formation of a compound nucleus is larger for neutrons than for charged particles because coulomb repulsion between the incident charged particles because coulomb repulsion between the incident charged particle and the target nucleus is important in the latter case. In the medium and heavy nuclei, the individual level becomes broader ad levels become more closer when the energy of the incident particle is large. The continuum theory nuclear reaction cross-sections treats the individual level not separately but as an average over many resonances.

The nucleus is described by an absorption coefficient σ which gives the probability per unit time that an incident particle becomes amalgamated with the nucleus . This absorption coefficient appears as an imaginary potential in the Schrödinger equation. It is shown that a gradual decrease of σ at the nuclear boundary is essential for achieving agreement with experiments. This model gives automatically unit sticking probability for fast neutrons, a cross section proportional to 1v for slow neutrons, and no one-particle resonances for particles which have to penetrate a potential barrier. Quantitative calculations are made with σ varying as $e^{-(r-R)b}$ outside the nucleus. For neutrons of zero orbital momentum, the formation probability of the compound nucleus is found to be $\zeta=1-e^{-2\pi kb}$ where k is the wave number. It is significant that ζ depends on the diffuseness b of the nuclear boundary rather than on the nuclear radius R. On the other hand, the factor 2π ensures that ζ is close to unity already for energies of about 1 Mev . The total cross section in the region of overlapping levels, and the average level width in the region of separated levels are expressed in terms of the formation probability ζ. The relation with the elastic scattering is discussed . The case of slow neutrons is treated in detail. With an average spacing D of 10 volts between levels of the same J, the average neutron width is about 2×10^{-3E12} for a neutron energy E, in rough agreement with the meager experimental data. With these assumptions, the neutron width will become larger than the radiation width already for E≈103 ev; experiments on the capture of "medium fast" neutrons (≈2×105 ev) can be interpreted roughly on this basis.

The elastic potential scattering of slow neutrons is shown to be equivalent to the scattering from a hard sphere whose radius R′ is defined by the condition that $\sigma(R')=(\hbar^2 mb^2)e^{-2C}$ where C is Euler's constant 0.577. The case of particles which move in a non-nuclear potential V (electrostatic or centrifugal) is treated in for various relations between the energy E of the incident particle and the height V(R′) of the potential barrier. If E−V(R′) is more than about 1 Mev, the formation probability is close to one, as for a fast neutron . If E is about equal to V(R′), ζ is still of the order of unity . For E<V(R′), ζ contains the well-known penetrability of the potential barrier, $e^{-2G,}$ aside from other factors which increase slowly with |E−V(R′)| . The magnitude of σ inside the nucleus is derived for the case of extremely high energies from the Born approximation and the variation of σ with energy is shown to be slight in this case. Although quantitative conclusions on the case of moderate energies cannot be drawn, it seems likely that σ is at least 20-40 Mev in that case. Finally, it is shown that no appreciable change of results is caused by an attractive or repulsive nuclear

potential added to the nuclear absorption potential . In the main part of the paper, it has been assumed that the average interaction between nucleus and particle is zero.

Stages of nuclear reaction:

Detailed theories of nuclear reaction were patterned after the two nuclear models. The liquid drop model and the shell model. In the compound nucleus theory it was assumed that a nuclear projectile incident on a nucleus would interact strongly with all the nucleons in the nucleus quickly share its energy with them. In the reaction theory, it was proposed that an incident nucleon would interact with the nucleus via the shell model potential. The success of the optical model suggests that the bohr theory of compound nucleus is in need of modification. A more general scheme of nuclear reaction has been described by Weisskopf. According t him the nuclear reaction proceeds through three stages: the independent particle stage, compound nucleus stage and the final stage.

During the first stage, the interaction between the incident wave and nuclear potential may lead to particle reflection of the incident wave, called shape elastic scattering. The part of the wave function which enters the nucleus undergoes absorption. This process leads to second stage. Some of the possible absorption process are: (1) ejection nucleons in a collision with incident particle a direct interaction, (2) multiple collisions of the incoming particle with several nucleons of the target nucleus, (3) the excitation of some type of collective motion,(4) the formation of compound nucleus, without remembering details of the initial stage of formation.

The third stage of the reaction is the more or less rapid transitions to the final stage. It is concerned with the way the reaction products are produced . either disintegration or de-excitation of the compound nucleus will occur. Actually there is no sharp division between the different possibilities in a compound system.

Direct reactions:(stripping and pickup reaction):

Nuclear reactions, that occur in a **time comparable to the time of transit** of an incident particle across the nucleus ($\sim10^{-22}$s), are called **direct nuclear reactions.** Interaction time is critical for defining the reaction mechanism. The very short interaction time allows for an **interaction of a single nucleon** only (in extreme cases). In fact, there is always some non-direct (a multiple internuclear interaction) component in all reactions, but the direct reactions have this component limited. To limit the time available for multiple internuclear interactions, the reaction have to occur **at high energy.**

Direct reactions have another property which is very important. **Products** of a direct reaction **are not distributed isotropically in angle**, but they are forward focused. This reflects the fact that the projectiles makes only one, or very few, collisions with nucleons in the target nucleus and its forward momentum is not transferred to an entire compound state.

The cross-sections for direct reactions vary smoothly and slowly with energy in contrast to the compound nucleus reactions and these cross-sections are comparable to the geometrical cross-sections of target nuclei. Types of direct reactions:

- **Elastic scattering** in which a passing particle and a targes stay in their ground states.
- **Inelastic scattering** in which a passing particle changes its energy state. For example the (p, p') reaction.
- **Transfer reactions** in which one or more nucleons are transferred to the othes nucleus. These reactions are further classified to as:
    - **Stripping reaction** in which one or more nucleons are transferred to a target nucleus from passing particle. For example the neutron stripping in the (d, p) reaction.
    - **Pick-up reaction** in which one or more nucleons are transferred from a target nucleus to a passing particle. For example the neutron pick-up in the (p, d) reaction
- **Break-up reaction** in which a breakup of a projectile into two or more fragments occurs.
- **Knock-out reaction** in which a single nucleon or a light cluster is removed from the projectile by a collision with the target.

$$ {}^{1}_{0}n + {}^{10}_{5}B \xrightarrow{(E_k>1.2MeV)} {}^{3}_{1}H + {}^{4}_{2}He + {}^{4}_{2}He $$

Example: This threshold reaction of fast neutron with an isotope ^{10}B is one of the ways, how radioactive tritium in primary circuit of all PWRs is generated.

KARPAGAM ACADEMY OF HIGHER EDUCATION,COIMBATORE-21
DEPARTMENT OF PHYSICS
CLASS:I MSC PHYSICS
NUCLEAR PHYSICS (17PHP203)
MULIPLE CHOICE QUESTIONS

Unit - IV

QUESTIONS	**opt1**	**opt2**	**opt3**	**opt4**	**answer**
A proton cannot decay into a neutr	Energy (assume the proton is	Angular momentum	Charge	All the above	All the above
The following reaction: $^{1}n_{0}+ ^{235}U_{9}$	Fusion	Fission	Alpha decay	Beta decay	Fission
Four factor formula is given by	ηεpf	ηαpf	σΩpf	σΩpa	ηεpf
The effective area possessed by a n	Total nuclear cross-section	Total nuclear reaction	Scattering process	None of these	Total nuclear cross-section
A device in which nuclear fission c	Nuclear power house	Nuclear reactor	Nuclear transmissio	None of these	Nuclear reactor
Nuclear fuel, moderator control rod	Nuclear reactor	Nuclear power house	Nuclear energy	None of these	Nuclear reactor
The ratio of the number of fission p	K-factor or reproduction fac	Gain factor	Power factor	None of these	K-factor or reproduction factor
The following reaction: $^{2}H_{1}+^{3}H_{1}$ −	Fusion	Fission	Alpha decay	Beta decay	Fusion
What is fission?	The joining together of atom	The process of creating hea	The splitting of aton	The scientific creation of b	The splitting of atoms into smaller pieces.
Conservation laws that describe ev	energy	linear and angular momentu	electric charge	All of these are correct	All of these are correct
The initial fragments formed by fis	More protons than neutrons	More neutrons than protons	About the same num	Number of proton and neu	More neutrons than protons
Which of the potential fusion reacti	$^{6}Li + ^{6}Li$	$^{4}He + ^{4}He$	$^{20}Ne + ^{20}Ne$	$^{35}Cl + ^{35}Cl$	$^{35}Cl + ^{35}Cl$
A generic fission event is ^{235}U +n -	$^{141}Xe + ^{93}Sr$	$^{139}Cs + ^{95}Rb$	$^{156}Nd + ^{79}Ge$	None of these	$^{156}Nd + ^{79}Ge$
The following reaction: He_{2}^4+O_{8}	An elastic reaction	An inelastic scattering react	A pick up reaction	A stripping reaction	A stripping reaction
Typical energy released in a nuclea	50MeV and 1000MeV	200MeV and 1000MeV	1000MeV and 50M	200MeV and 10MeV	200MeV and 10MeV
The decay of n=p+e^{-1}	Cannot conserve angular mo	Can conserve angular mom	Data in sufficient	None of these	Cannot conserve angular momentum
Which of the following argument is	Statistics	Binding energy	Electron magnetic m	β-decay	Electron magnetic moment
A thermal neutron having speed ν i	ν^{-1}	ν	$\nu^{1/2}$	ν-$^{1/2}$	ν^{-1}
The disintegration series of the hea	Actinium series	Neptunium series	Thorium series	Uranium series	Neptunium series
Suppose that a neutron at rest in fre	conservation of charge	conservation of energy	conservation of linea	conservation of angular mo	conservation of linear momentum
The width of a nuclear excited state	inversely proportional to its	inversely proportional to its	Directly proportiona	Independent of half-life	inversely proportional to its mass
In a nuclear reaction, the mass of th	Always equal to the sum of t	Always less than the sum of	Always greater than	different from the sum of c	Always less than the sum of the masses of the colliding nuclei
Which among the following is true	All neutrinos are left handed	All neutrinos are right hand	There are both left h	No handedness is associate	All neutrinos are left handed and all antineutrinos are right handed
Find the incorrect statement	The nuclear force is spin dep	The bound state is the triple	The energy levels of	A system of two neutrons	The energy levels of triplet state is higher than singlet state
For controlled thermonuclear fusio	D+D→^{3}He+n+3.25MeV	D+D→T+p+4.0MeV	D+T→^{4}He+n+17.6	None of these	D+T→^{4}He+n+17.6MeV
Assume the neutrino mass is exactl	The neutrino have magnetic	The neutrino spin points alc	The antineutrino spi	The antineutrino spin poin	The antineutrino spin does the reverse of neutrino
An electron and a proton enter a ma	electron	Proton	Both experience san	Neither of them experience	Both experience same force
On the basis of Q values, determine	1.796MeV	0.662MeV	1.684MeV	None of these	1.796MeV
On the basis of Q values, determine	1.796MeV	0.662MeV	1.684MeV	None of these	0.662MeV
On the basis of Q values, determine	1.796MeV	0.662MeV	1.684MeV	None of these	1.684MeV
A 2MeV neutron is emitted in a fiss	23	24	25	26	26
Which of the following probe can p	Electrons	Proton	Neutrons	Photons	Photons
Which of the following is true for β	Violates both parity and char	Violates parity but conserv	Conserves parity but	Conserves both parity and	Violates both parity and charge conjugation symmetry
To penetrate the coulomb barrier of	1GeV	100MeV	10MeV	1MeV	1MeV
Identify the process which takes pla	Electron capture	Positron emission	Electron emission	γ-emission	Electron capture
In the classification of neutrons bas	Cold neutrons	Epithermal neutron	Resonance neutron	Thermal neutron	Resonance neutron
The kinetic energy of the α-particle	(A-4/A)Q	(4Q/A)	(AQ/4)	(Q/4A)	(A-4/A)Q
Masses of two isobars $_{29}Cu^{64}$ and $_{30}$	Both the isobars are stable	Zn^{64} is radioactive decaying	Cu^{64} is radioactive d	Cu^{64} is radioactive decayin	Cu^{64} is radioactive decaying to Zn^{64} through β-decay
The reaction $^{12}C_{6}+^{1}H_{1} \rightarrow ^{13}N_{6}+\gamma$ is	Capture reaction	Particle-particle reaction	Fission reaction	Fusion reaction	Capture reaction

If Q is –ve, reaction involved is	Endo-ergic	Exoergic	neutral	None of these	Endo-ergic
The theory of low energy deuteron	Thomson	Oppenheimer and Phillips	Seaborg	Yukawa	Oppenheimer and Phillips
The inverse of the stripping reactio	Pick-up reaction	Nuclear reaction	Endothermic reactio	Exoergic reaction	Pick-up reaction
The energy dependence the cross s	Bethe-Bloch formula	Breit-Wigner formula	Gamous-Teller form	Bethe-Weizacker formula	Breit-Wigner formula
The antiparticle of an electron is th	Anderson	Yukawa	J.J.Thomson	Einstein	Anderson
When the projectile gains nucleons	Stripping reaction	Pickup reaction	Exoergic reaction	None of these	Pickup reaction
When the projectile loses nucleons	Stripping reaction	Pickup reaction	Exoergic reaction	None of these	Stripping reaction
The analytic relationship between t	Q equation	scattering equation	reaction cross sectio	none of these	Q equation
The scattering of alpha particles in	inelastic scattering	disintegration	radiative capture	elastic scattering	elastic scattering
If the sum of the masses of incident	exoergic	endoergic	exoergic or endoerg	none of these	exoergic
Breit-Wigner formula leads to the c	target energy	neutron spin	neutron energy	neutron angular momentum	neutron energy
The cross section which defines a d	partial cross section	differential cross section	Total cross section	all the above	differential cross section
when a nucleus is excited, excited e	Nuclear temperature	excitation temperature	temperature coeffici	none of these	Nuclear temperature

Prepared by Dr. B. Janarthanan, Associate Professor, Department of Physics, KAHE

UNIT-V

SYLLABUS

High energy physics : Types of interaction in nature-typical strengths and time-scales, conservation laws, charge-conjugation, Parity and Time reversal, CPT theorem, GellMann-Nishijima formula, intrinsic parity of pions, resonances, symmetry classification of elementary particles, quark hypothesis, charm, beauty and truth, gluons, quark confinement, asymptotic freedom

Types of interactions:

The gravitational interaction:

Gravitation is by far the weakest of the four interactions at the atomic scale, where electromagnetic interactions dominate. But the idea that the weakness of gravity can easily be demonstrated by suspending a pin using a simple magnet (such as a refrigerator magnet) is fundamentally flawed. The only reason the magnet is able to hold the pin against the gravitational pull of the entire Earth is due to its relative proximity. There is clearly a short distance of separation between magnet and pin where a breaking point is reached, and due to the large mass of Earth this distance is disappointingly small.

Thus gravitation is very important for macroscopic objects and over macroscopic distances for the following reasons. Gravitation:

Is the only interaction that acts on all particles having mass, energy and/or momentum

Has an infinite range, like electromagnetism but unlike strong and weak interaction

Cannot be absorbed, transformed, or shielded against

Always attracts and never repels (see function of geodesic equation in general relativity)

Electromagnetism:

Electromagnetism is the force that acts between electrically charged particles. This phenomenon includes the electrostatic force acting between charged particles at rest, and the combined effect of electric and magnetic forces acting between charged particles moving relative to each other.

Electromagnetism is infinite-ranged like gravity, but vastly stronger, and therefore describes a number of macroscopic phenomena of everyday experience such as friction, rainbows, lightning, and all human-made devices using electric current, such as television, lasers, and computers. Electromagnetism fundamentally determines all macroscopic, and many atomic levels, properties of the chemical elements, including all chemical bonding.

Strong interaction:

The strong interaction, or strong nuclear force, is the most complicated interaction, mainly because of the way it varies with distance. At distances greater than 10 femtometers, the strong force is practically unobservable. Moreover, it holds only inside the atomic nucleus.

After the nucleus was discovered in 1908, it was clear that a new force, today known as the nuclear force, was needed to overcome the electrostatic repulsion, a manifestation of electromagnetism, of the positively charged protons. Otherwise, the nucleus could not exist. Moreover, the force had to be strong enough to squeeze the protons into a volume that is about 10−15 m, much smaller than that of the entire atom. From the short range of this force, Hideki Yukawa predicted that it was associated with a massive particle, whose mass is approximately 100 MeV.

Weak interaction:

The weak interaction or weak nuclear force is responsible for some nuclear phenomena such as beta decay. Electromagnetism and the weak force are now understood to be two aspects of a unified electroweak interaction — this discovery was the first step toward the unified theory known as the Standard Model. In the theory of the electroweak interaction, the carriers of the weak force are the massive gauge bosons called the W and Z bosons. The weak interaction is the only known interaction which does not conserve parity; it is left-right asymmetric. The weak interaction even violates CP symmetry but does conserve CPT.

Strengths and time scale:

Interaction	Current theory	Mediators	Relative strength[7]	Long-distance behavior	Range (m)[citation needed]
Strong	Quantum chromodynamics (QCD)	gluons	1038	{\displaystyle {\sim r}} (Color confinement, see discussion below)	10−15
Electromagnetic	Quantum electrodynamics (QED)	photons	1036	{\displaystyle {\frac {1}{r^{2}}}}	∞
Weak	Electroweak Theory (EWT)	W and Z bosons	1025	{\displaystyle {\frac {1}{r}}\ e^{-m_{W,Z}\ r}}	10−18
Gravitation	General relativity (GR)	gravitons (hypothetical)	1	{\displaystyle {\frac {1}{r^{2}}}}	∞

Conservation laws:

Conservation laws are critical to an understanding of particle physics. Strong evidence exists that energy, momentum, and angular momentum are all conserved in all particle interactions. The annihilation of an electron and positron at rest, for example, cannot produce just one photon because this violates the conservation of linear momentum. As discussed in Relativity, the special theory of relativity modifies definitions of momentum, energy, and other familiar quantities. In particular, the relativistic momentum of a particle differs from its classical momentum by a factor γ=1/1−(v/c)2−−−−−−−−√γ=1/1−(v/c)2 that varies from 1 to ∞∞, depending on the speed of the particle.

In previous chapters, we encountered other conservation laws as well. For example, charge is conserved in all electrostatic phenomena. Charge lost in one place is gained in another because charge is carried by particles. No known physical processes violate charge conservation. In the next section, we describe three less-familiar conservation laws: baryon number, lepton number, and strangeness. These are by no means the only conservation laws in particle physics.

Conservation of Baryon Number:

Nature has specific rules for particle interactions and decays, and these rules have been summarized in terms of conservation laws. One of the most important of these is the conservation of baryon number. Each of the baryonsis assigned a baryon number B=1. This can be considered to be equivalent to assigning each quark a baryon number of 1/3. This implies that the mesons, with one quark and one antiquark, have a baryon number B=0. No known decay process or interaction in nature changes the net baryon number.

The neutron and all heavier baryons decay directly to protons or eventually form protons, the proton being the least massive baryon. This implies that the proton has nowhere to go without violating the conservation of baryon number, so if the conservation of baryon number holds exactly, the proton is completely stable against decay. One prediction of grand unification of forces is that the proton would have the possibility of decay, so that possibility is being investigated experimentally.

Conservation of baryon number prohibits a decay of the type

$$p + n \rightarrow p + \mu^+ + \mu^-$$
$$B = 1 + 1 \neq 1 + 0 + 0$$

but with sufficient energy permits pair production in the reaction

$$p + n \rightarrow p + n + p + \overline{p}$$
$$B = 1 + 1 = 1 + 1 + 1 - 1$$

The fact that the decay

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$

is observed implied that there is no corresponding principle of conservation of meson number. The pion is a meson composed of a quark and an antiquark, and on the right side of the equation there are only leptons. (Equivalently, you could assign a baryon number of 0 to the meson.)

Conservation of Lepton Number:

Nature has specific rules for particle interactions and decays, and these rules have been summarized in terms of conservation laws. One of the most important of these is the conservation of lepton number. This rule is a little more complicated than the conservation of baryon number because there is a separate requirement for each of the three sets of leptons, the electron, muon and tau and their associated neutrinos.

The first significant example was found in the decay of the neutron. When the decay of the neutron into a proton and an electron was observed, it did not fit the pattern of two-particle decay. That is, the electron emitted does not have a definite energy as is required by conservation of energy and momentum for a two-body decay. This implied the emission of a third particle, which we now identify as the electron antineutrino.

$$n \not\rightarrow p^+ + e^-$$
$$n \rightarrow p^+ + e^- + \bar{\nu}_e$$

The assignment of a lepton number of 1 to the electron and -1 to the electron antineutrino keeps the lepton number equal to zero on both sides of the second reacton above, while the first reaction does not conserve lepton number.

The observation of the following two decay processes leads to the conclusion that there is a separate lepton number for muons which must also be conserved.

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$

$$\mu^- \rightarrow e^- + \bar{\nu}_e + \nu_\mu$$

The first reaction above (decay of the pion) is known to be a two-body decay by the fact that a well-defined muon energy is observed from the decay. However, the decay of the muon into an electron produces a distribution of electron energies, showing that it is at least a three-body decay. In order for both electron lepton number and muon lepton number to be conserved, then the other particles must be an electron anti-neutrino and a muon neutrino.

Isospin:

Isospin is a term introduced to describe groups of particles which have nearly the same mass, such as the proton and neutron. This doublet of particles is said to have isospin 1/2, with projection +1/2 for the proton and -1/2 for the neutron. The three pions compose a triplet, suggesting isospin 1. The projections are +1 for the positive, 0 and -1 for the neutral and negative pions. Isospin is used as an axis in particle diagrams, with strangeness being the other axis. Isospin is not really spin, and doesn't have the units of angular momentum - the spin term is tacked on because the addition of the isospins follows the same rules as spin.

Isospin is a dimensionless quantity associated with the fact that the strong interaction is independent of electric charge. Any two members of the proton-neutron isospin doublet experience the same strong interaction: proton-proton, proton-neutron, neutron-neutron have the same strong force attraction.

At the quark level, the up and down quarks form an isospin doublet (I=1/2) and the projection I3 = +1/2 is assigned to the up quark and I3 =-1/2 to the down. (The subscript 3 is used here for the third component rather than the z used with spin and orbital angular momentum because most of the literature does so.) The other quarks are assigned isospin I=0. Isospin is related to other quantum numbers for the particles by

$$\frac{q}{e} = I_3 + \frac{S+B}{2}$$

I_3 = projection of isotopic spin

S = strangeness

B = baryon number

q = charge (q/e used to make it dimensionless)

This relationship is called the Gell Mann-Nishijima formula. Some references use T for isospin, but it appears that most use I for isospin and T for weak isospin.

Isospin is associated with a conservation law which requires strong interaction decays to conserve isospin, as illustrated by the process

$$\begin{array}{ccc} uds & & uds \\ \Sigma^0 & \rightarrow & \Lambda^0 + \gamma \\ I=1 & \neq & I=0 \end{array}$$

which does not involve any transmutation of quarks, so would be expected to decay by strong interaction. However, it does not conserve isospin, and is observed to decay by the electromagnetic interaction, but not by the strong interaction. The experimental discrimination is made by the observation of its decay lifetime, presuming by the totalitarian principle that if it could decay by the strong interaction, it would.

Parity:

One of the conservation laws which applies to particle interactions is associated with parity. Quarks have an intrinsic parity which is defined to be +1 and for an antiquark parity = -1. Nucleons are defined to have intrinsic parity +1. For a meson with quark and antiquark with antiparallel spins (s=0), then the parity is given by

$$P = P_q P_{\bar{q}} (-1)^{\ell} \quad \text{where } \ell = \text{orbital angular momentum}$$

The meson parity is given by

$$P = -(-1)^{\ell} = (-1)^{\ell+1}$$

The lowest energy states for quark-antiquark pairs (mesons) will have zero spin and negative parity and are called pseudoscalar mesons. The nine pseudoscalar mesons can be shown on a meson diagram. One kind of notation for these states indicates their angular momentum and parity

$$j^P = 0^-$$

Excited states of the mesons occur in which the quark spins are aligned, which with zero orbital angular momentum gives j=1. Such states are called vector mesons.

$j^P = 1^-$

The vector mesons have the same spin and parity as photons.

All neutrinos are found to be "left-handed", with an intrinsic parity of -1 while antineutrinos are right-handed, parity =+1.

Charge Conjugation:

Associated with the conservation laws which govern the behavior of physical particles, charge conjugation (C), parity (P) and time reversal (T) combine to constitute a fundamental symmetry called CPT invariance.

Classically, charge conjugation may seem like a simple idea: just replace positive charges by negative charges and vice versa. Since electric and magnetic fields have their origins in charges, you also must reverse these fields.

In quantum mechanical systems, charge conjugation has some further implications. It also involves reversing all the internal quantum numbers like those for lepton number, baryon number and strangeness. It does not affect mass, energy, momentum or spin.

Thinking of charge conjugation as an operator, C, then electromagnetic processes are invariant under the C operation since Maxwell's equations are invariant under C. This restricts some kinds of particle processes. Das and Ferbel proceed by defining a charge parity of $\eta C(\gamma) = -1$ for a photon since the C operation reverses the electric field. This constrains the electromagnetic decay of a neutral particle like the $\pi 0$. The decay of the $\pi 0$ is:

$\pi 0 \rightarrow \gamma + \gamma$

This implies that the charge parity or behavior under charge conjugation for a $\pi 0$ is:

$\eta C(\pi 0) = \eta C(\gamma)\eta C(\gamma) = (-1)2 = +1$

Charge conjugation symmetry would imply that the $\pi 0$ will not decay by

$\pi 0 \rightarrow \gamma$

which we already know because it can't conserve momentum, but the decay

$\pi 0 \rightarrow \gamma + \gamma + \gamma$

can conserve momentum. This decay cannot happen because it would violate charge conjugation symmetry.

While the strong and electromagnetic interactions obey charge conjugation symmetry, the weak interaction does not. As an example, neutrinos are found to have intrinsic parities: neutrinos have left-handed parity and antineutrinos right-handed. Since charge conjugation would leave the spatial coordinates untouched, then if you operated on a neutrino with the C operator, you would produce a left-handed antineutrino. But there is no experimental evidence for such a particle; all antineutrinos appear to be right-handed. The combination of the parity operation P and the charge conjugation operation C on a neutrino do produce a right-handed antineutrino, in accordance with observation. So it appears that while beta decay does not obey parity or charge conjugation symmetry separately, it is invariant under the combination CP.

Time Reversal:

Associated with the conservation laws which govern the behavior of physical particles, charge conjugation (C), parity (P) and time reversal combine to constitute a fundamental symmetry called CPT invariance.

In simple classical terms, time reversal just means replacing t by -t, inverting the direction of the flow of time. Reversing time also reverses the time derivatives of spatial quantities, so it reverses momentum and angular momentum.Newton's second law is quadratic in time and is invariant under time reversal. It's invariance under time reversal holds for either gravitational or electromagnetic forces.

Very sensitive experimental tests have been done to put upper bounds on any violation of time-reversal symmetry. One experiment described by Das and Ferbel is the search for a dipole moment for the neutron. Even though the neutron is neutral, it is viewed as made up of charged quarks and therefore could conceivably have a dipole moment. Experimental evidence is consistent with zero dipole moment, so time reversal symmetry seems to hold in this case.

The small violation of CP symmetry suggests some departure from T symmetry in some weak interaction process since CPT invariance seems to be on very firm ground.

Parity or space inversion invariance:

One of the conservation laws which applies to particle interactions is associated with parity.

Quarks have an intrinsic parity which is defined to be +1 and for an antiquark parity = -1. Nucleons are defined to have intrinsic parity +1. For a meson with quark and antiquark with antiparallel spins (s=0), then the parity is given by

$$P = P_q P_{\bar{q}} (-1)^{\ell} \quad \text{where } \ell = \text{orbital angular momentum}$$

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The lowest energy states for quark-antiquark pairs (mesons) will have zero spin and negative parity and are called pseudoscalar mesons. The nine pseudoscalar mesons can be shown on a meson diagram. One kind of notation for these states indicates their angular momentum and parity

$$j^P = 0^-$$

Excited states of the mesons occur in which the quark spins are aligned, which with zero orbital angular momentum gives j=1. Such states are called vector mesons.

$$j^P = 1^-$$

The vector mesons have the same spin and parity as photons.

All neutrinos are found to be "left-handed", with an intrinsic parity of -1 while antineutrinos are right-handed, parity =+1

CPT Invariance:

Many of the profound ideas in nature manifest themselves as symmetries. A symmetry in a physical experiment suggests that something is conserved, or remains constant, during the experiment. So conservation laws and symmetries are strongly linked.

Three of the symmetries which usually, but not always, hold are those of charge conjugation (C), parity (P), and time reversal (T):

Charge conjugation(C): reversing the electric charge and all the internal quantum numbers.

Parity (P): space inversion; reversal of the space coordinates, but not the time.

Time reversal (T): replacing t by -t. This reverses time derivatives like momentum and angular momentum.

Examples in nature can be cited for the violation of each of these symmetries individually. It was thought for a time that CP (parity transformation plus charge conjugation) would always leave a system invariant, but the notable example of the neutral kaons has shown a slight violation of CP symmetry.

We are left with the combination of all three, CPT, a profound symmetry consistent with all known experimental observations.

On the theoretical side, CPT invariance has received a great deal of attention. Georg Ludens, Wolfgang Pauli and Julian Schwinger independently showed that invariance under Lorentz transformations implies CPT invariance. CPT invariance itself has implications which are at the heart of our understanding of nature and which do not easily arise from other types of considerations.

Integer spin particles obey Bose-Einstein statistics and half-integer spin particles obey Fermi-Dirac statistics. Operators with integer spins must be quantized using commutation relations, while anticommutation relations must be used for operators with half integer spin.

Particles and antiparticles have identical masses and lifetimes. This arises from CPT invariance of physical theories.

All the internal quantum numbers of antiparticles are opposite to those of the particles

Gell-Mann–Nishijima formula:

The Gell-Mann–Nishijima formula (sometimes known as the NNG formula) relates the baryon number B, the strangeness S, the isospin I3 of quarks and hadrons to the electric charge Q. It was originally given by Kazuhiko Nishijima and Tadao Nakano in 1953,[1] and led to the proposal of strangeness as a concept, which Nishijima originally called "eta-charge" after the eta meson.[2] Murray Gell-Mann proposed the formula independently in 1956.[3] The modern version of the formula relates all flavor quantum numbers (isospin up and down, strangeness, charm, bottomness, and topness) with the baryon number and the electric charge.

The original form of the Gell-Mann–Nishijima formula is:

$$Q = I3+1/2\ (B+S)$$

This equation was originally based on empirical experiments. It is now understood as a result of the quark model. In particular, the electric charge Q of a quark or hadron particle is related to its isospin I3 and its hypercharge Y via the relation:

$$Q = I3+1/2\ Y$$

$$Y = 2(Q-I3)$$

Since the discovery of charm, top, and bottom quark flavors, this formula has been generalized. It now takes the form:

$$Q = I3+1/2(B+S+C+B'+T)$$

where Q is the charge, I3 the 3rd-component of the isospin, B the baryon number, and S, C, B′, T are the strangeness, charm, bottomness and topness numbers.

Resonance:

In particle physics, a resonance is the peak located around a certain energy found in differential cross sections of scattering experiments. These peaks are associated with subatomic particles, which include a variety of bosons, quarks and hadrons (such as nucleons, delta baryons or upsilon mesons) and their excitations. In common usage, "resonance" only describes particles with very short lifetimes, mostly high-energy hadrons existing for 10−23 seconds or less. The width of the resonance (Γ) is related to the mean lifetime (τ) of the particle (or its excited state) by the relation

$$\Gamma = ħ/T$$

{\displaystyle \Gamma ={\frac {\hbar }{\tau }}} {\displaystyle {\hbar }={\frac {h}{2\pi }}}

Thus, the lifetime of a particle is the direct inverse of the particle's resonance width. For example, the charged pion has the second-longest lifetime of any meson, at 2.6033×10−8 s.[2] Therefore, its resonance width is very small, about 2.528×10−8 eV or about 6.11 MHz. Pions are generally not considered as "resonances". The charged rho meson has a very short lifetime, about 4.41×10−24 s. Correspondingly, its resonance width is very large, at 149.1 MeV or about 36 ZHz. This amounts to nearly one-fifth of the particle's rest mass.

Symmetry classification of elementary particles:

A major development in theoretical physics this century was the construction of what are called quantum field theories—theories of particles and their interactions that incorporate the probabilistic laws of quantum mechanics, special relativity, and the symmetries discussed above. This enterprise began soon after the discovery of quantum mechanics in the late 1920s. The quantum field theory of electromagnetism, describing the electron and the photon, reached its final form in the late 1940s, but theories involving larger local internal symmetries were not fully understood until the early 1970s. Quantum field theories are the basic tool for theoretical particle physicists. There are many such theories, and the great variety of phenomena they can describe is the subject of continuing research.

The Standard Model is a quantum field theory that provides a concise and accurate description of all known particle phenomena. This discussion relies on the ideas of symmetry and interaction vertices introduced in the previous section.

Three local internal symmetries have been discovered in nature: They are called strong, weak, and electromagnetic, after the three forces to which they give rise.

Strong symmetry leads to force particles of the strong interactions—the gluons, g. The matter particles that feel this force are called up and down quarks, u and d, and come in red, green and blue varieties. The gluon vertex for the up quark is illustrated in A quark of one color goes into the interaction and comes out as a quark of a different color, but its other properties are not changed. The mathematical theory of quarks and gluons that underlies this vertex is called "quantum chromodynamics," or QCD for short. The strength of the gluon interaction is called g3. It is large, making this QCD interaction strong. The matter particles that do not feel this strong force are leptons: the electron, e, and its neutrino, ve, as well as their second- and third-generation counterparts, the muon and tau, and their respective neutrinos.

The force particles of the weak interaction, the W and Z bosons. are very massive, which results in a force with a very short range—much less than the

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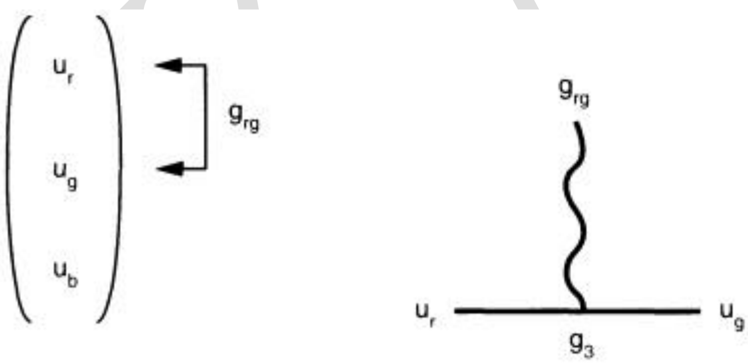

FIGURE 3.5 Quark triplets and the gluon vertex.

diameter of a proton. The electromagnetic interaction, on the other hand, has a massless force particle, the photon, with a corresponding range of interaction that is infinite, allowing us to see to the edge of the universe. A single parameter g2 describes the strength of the weak interactions , whereas g1 gives the strength of the electromagnetic interaction.

The weak symmetry has a very peculiar property. Only counterclockwise spinning (left-handed) quarks and leptons feel the weak force. The reason nature treats left-handed and right-handed objects differently is one of the many questions about the nature of forces for which we have as yet no adequate answers.

As indicated earlier, symmetries dictate both the forces and the so-called multiplet structure of particles that feel these forces summarizes this information about how the three forces that arise from local internal symmetries relate to the four basic types of matter particle (u, d, e, Ve,). For strong and weak forces, the entries represent the size of the multiplet of particles that interacts with the corresponding force particles. The strong force acts among triplets of quarks (three colors), changing one into the other; the weak force acts between quark and lepton doublets, again changing one into the other. An entry "I" implies that there is no interaction, since there is nothing to change into. Electromagnetic force acts on all particles except neutrinos (not changing their nature), and the entry in gives the electric charges of particles.

represents the limit reached at present in the quest for a simple understanding of particle interactions. There are several questions that this knowledge raises, questions that are not answered by the Standard Model: Why is it that some particles feel the strong force and some do not? Why are the weak interactions left-handed? Why are there not multiplets having more than three components? In short, why are the matter particles what they are, and why do they interact with force particles in the way shown in This table offers a mystifying array of numbers—how can it be understood?

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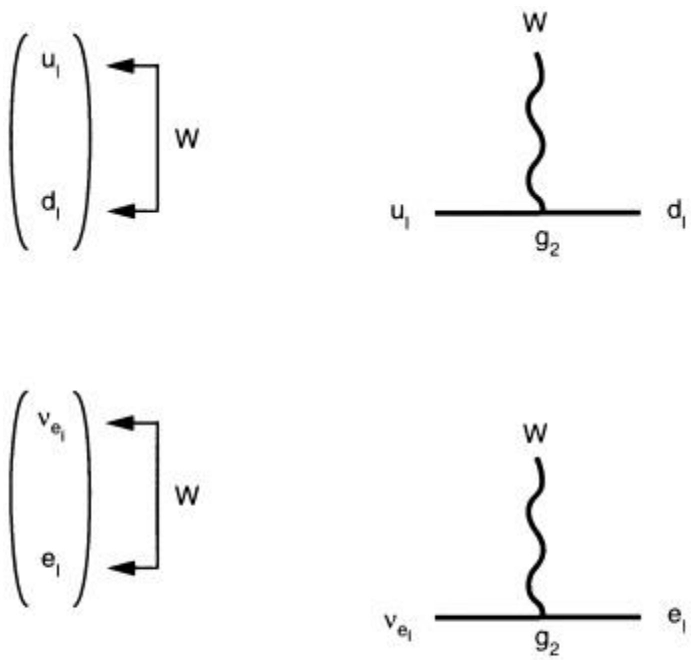

FIGURE 3.6 Left-handed doublets and the weak vertices.

The four matter particles discussed so far (u,d, e, ve) are the members of the first family, or generation, of particles. Three such generations of particles have been found, as shown in . The only known difference between the three generations is their mass-in particular, the force particle vertices of the heavier generations are identical to those of Figures 3.4, 3.5, and 3.6 for the lightest generation. This replication of particles suggests to some that there is a new internal symmetry to be discovered that is responsible for the different generations. Physicists believe that some deeper understanding of the three rows, or periods, of will eventually be found, in the same way that the revolution of quantum mechanics led to an understanding of the periodic table of the elements. In contrast, the particles of a single generation cannot be grouped into subgroups or periods of particles with similar properties- does not have a periodic structure.

In 1963, a theory was proposed that a major group of these particles, called hadrons, could be thought of as made from a few, more fundamental particles, called quarks. Protons and neutrons are members of the hadron group. Quarks are proposed to be the simplest, irreducible, structureless building blocks of hadrons. The Quark Hypothesis states that quarks in combinations of two or three, make all the observed hadrons. In 1963, the three quarks were named: up (u), down (d), and strange (s). In 1974, the existence of Charm quark (c) was revealed and in 1977, Leon Lederman and his collegues at Fermilab uncovered the fifth quark, bottom (b). A neutron is composed of three quarks: u d d; a proton is u u d; and a lambda is u d s. One more quark, top (t), has been found at Fermilab in 1995.

QUARK HYPOTHESIS:

Electrons, neutrinos, and a few other particles make up another group of particles called leptons. Leptons are not considered divisible and are not made up of quarks. The results of particle physicists' theoretical and experimental work up to 1985 might be summarized this way:

All matter is thought to be made up of quarks and leptons and the forces through which they interact. There are six quarks (each comes in three "colors" making 18 particles and each has an antiparticle making 36 quarks in total.) The six quarks are named up (u), down (d), strange (s), charm (c), bottom (b), and top (t). (The last two are sometimes fancifully referred to as "beauty" and "truth.") The six quarks have been confirmed through indirect observations, but not isolated as individual particles.

The other six particles (also appearing in antiparticle form, making 12 total) are the leptons. These include electrons (e), electron neutrinos (ue), muons (m), muon neutrinos (um), tau particles (t), and tau neutrinos (ut). The twelve particles (48 in all if you include colors and antiparticles) are subject to the four fundamental forces of nature. These forces are gravity, electromagnetic, strong, and weak. Each force is defined by the way it interacts with particles to build up composite form of matter: protons, neutrons, nuclei, atoms, molecules, planets, stars, and so on.

Each of the forces has a strength, a range, and a "carrier" particle as outlined in the table below.

Force (Weakest to Strongest	Range	Carrier	Observed
Gravity	All Distances	Graviton	No
Weak	Nuclear Distances	W+, W-, Z	Yes (1983)
Electromagentic	All Distances	Photon	Yes (1923)
Strong	Nuclear Distances	Gluon	Yes (1978) (Indirect)

One of the fundamental quests of the Fermilab scientists is to find an underlying link to unify the four basic forces. This Unification Theory would link all particles and forces into a coherent and simple description of nature. In order to "observe" the basic particles of matter and collect data which may be of use toward theory development and perhaps the Unification Theory, particle probes with great amounts of energy are needed. The protons with 1000 GeV (1 TeV) energy now available in Fermilab's accelerator will help in this quest. By creating head-on collisions between these protons and 1000 GeV antiprotons (generated earlier in stationary target collisions in a nearby storage ring) circulating in the opposite direction, 2000 GeV collision data will be generated. The main purpose of Fermilab and other large particle accelerators is to collect data that will support or refute theories. The need for new and better data is continuous. Numerous experiments remain to be done and each new theory and the related attempts at experimental verification inevitably lead to new insights as well as new questions about the most fundamental particles and forces that form all matter.

Asymptotic freedom:

In particle physics, **asymptotic freedom** is a property of some gauge theories that causes interactions between particles to become asymptotically weaker as the energy scale increases and the corresponding length scale decreases.

Asymptotic freedom is a feature of quantum chromodynamics (QCD), the quantum field theory of the strong interaction between quarks and gluons, the fundamental constituents of nuclear matter. Quarks interact weakly at high energies, allowing perturbative calculations. At low energies the interaction becomes strong, leading to the confinement of quarks and gluons within composite hadrons.

The asymptotic freedom of QCD was discovered in 1973 by David Gross and Frank Wilczek,[1] and independently by David Politzer in the same year.[2] For this work all three shared the 2004 Nobel Prize in Physics.

Calculating of Asymptotic freedom:

Asymptotic freedom can be derived by calculating the beta-function describing the variation of the theory's coupling constant under the renormalization group. For sufficiently short distances or large exchanges of momentum (which probe short-distance behavior, roughly because of the inverse relation between a quantum's momentum and De Broglie wavelength), an asymptotically free theory is amenable to perturbation theory calculations using Feynman diagrams. Such situations are therefore more theoretically tractable than the long-distance, strong-coupling behavior also often present in such theories, which is thought to produce confinement.

Calculating the beta-function is a matter of evaluating Feynman diagrams contributing to the interaction of a quark emitting or absorbing a gluon. Essentially, the beta-function describes how the coupling constants vary as one scales the system . The calculation can be done using rescaling in position space or momentum space (momentum shell integration). In non-abelian gauge theories such as QCD, the existence of asymptotic freedom depends on the gauge group and number of flavors of interacting particles.

Finally, one can find theories that are asymptotically free and reduce to the full Standard Model of electromagnetic, weak and strong forces at low enough energies.

Confinement of Quarks:

How can one be so confident of the quark model when no one has ever seen an isolated quark? There are good reasons for the lack of direct observation. Apparently the color forcedoes not drop off with distance like the other observed forces. It is postutated that it may actually increase with distance at the rate of about 1 GeV per fermi. A free quark is not observed because by the time the separation is on an observable scale, the energy is far above the pair production energy for quark-antiquark pairs. For the U and D quarks the masses are 10s of MeV so pair production would occur for distances much less than a fermi. You would expect a lot of mesons (quark-antiquark pairs) in very high energy collision experiments and that is what is observed.

Basically, you can't see an isolated quark because the color force does not let them go, and the energy required to separate them produces quark-antiquark pairs long before they are far enough apart to observe separately.

One kind of visualization of quark confinement is called the "bag model". One visualizes the quarks as contained in an elastic bag which allows the quarks to move freely around, as long as you don't try to pull them further apart. But if you try to pull a quark out, the bag stretches and resists.

Another way of looking at quark confinement is expressed by Rohlf. "When we try to pull a quark out of a proton, for example by striking the quark with another energetic particle, the quark experiences a potential energy barrier from the strong interaction that increases with distance." As the example of alpha decay demonstrates, having a barrier higher than the particle energy does not prevent the escape of the particle - quantum mechanical tunnelinggives a finite probability for a 6 MeV alpha particle to get through a 30 MeV high energy barrier. But the energy barrier for the alpha particle is thin enough for tunneling to be effective. In the case of the barrier facing the quark, the energy barrier does not drop off with distance, but in fact increases.

Gluons:

Gluons are the exchange particles for the color force between quarks, analogous to the exchange of photons in the electromagnetic force between two charged particles. The gluon can be considered to be the fundamental exchange particle underlying the strong interactionbetween protons and neutrons in a nucleus. That short-range nucleon-nucleon interaction can be considered to be a residual color force extending outside the boundary of the proton or neutron. That strong interaction was modeled by Yukawa as involving an exchange of pions, and indeed the pion range calculation was helpful in developing our understanding of the strong force.

Group theory:

Technically, QCD is a gauge theory with SU(3) gauge symmetry. Quarks are introduced as spinors in Nf flavors, each in the fundamental representation (triplet, denoted 3) of the color gauge group, SU(3). The gluons are vectors in the adjoint representation (octets, denoted 8) of color SU(3). For a general gauge group, the number of force-carriers (like photons or gluons) is always equal to the dimension of the adjoint representation. For the simple case of SU(N), the dimension of this representation is N2 − 1.

In terms of group theory, the assertion that there are no color singlet gluons is simply the statement that quantum chromodynamics has an SU(3) rather than a U(3) symmetry. There is no known a priori reason for one group to be preferred over the other, but as discussed above, the experimental evidence supports SU(3). The U(1) group for electromagnetic field combines with a slightly more complicated group known as SU(2) – S stands for "special" – which means the corresponding matrices have determinant 1 in addition to being unitary.

Confinement:

Since gluons themselves carry color charge, they participate in strong interactions. These gluon-gluon interactions constrain color fields to string-like objects called "flux tubes", which exert constant force when stretched. Due to this force, quarks are confined within composite particles called hadrons. This effectively limits the range of the strong interaction to 1×10^{-15} meters, roughly the size of an atomic nucleus. Beyond a certain distance, the energy of the flux tube binding two quarks increases linearly. At a large enough distance, it becomes energetically more favorable to pull a quark-antiquark pair out of the vacuum rather than increase the length of the flux tube.

Gluons also share this property of being confined within hadrons. One consequence is that gluons are not directly involved in the nuclear forces between hadrons. The force mediators for these are other hadrons called mesons.

Although in the normal phase of QCD single gluons may not travel freely, it is predicted that there exist hadrons that are formed entirely of gluons — called glueballs. There are also conjectures about other exotic hadrons in which real gluons (as opposed to virtual ones found in ordinary hadrons) would be primary constituents. Beyond the normal phase of QCD (at extreme temperatures and pressures), quark–gluon plasma forms. In such a plasma there are no hadrons; quarks and gluons become free particles.

Charm, beauty and truth – quarks:

The baryons and mesons are complex subatomic particles built from more-elementary objects, the quarks. Six types of quark, together with their corresponding antiquarks, are necessary to account for all the known hadrons. The six varieties, or "flavours," of quark have acquired the names up, down, charm, strange, top, and bottom. The meaning of these somewhat unusual names is not important; they have arisen for a number of reasons. What is important is the way that the quarks contribute to matter at different levels and the properties that they bear.

The quarks are unusual in that they carry electric charges that are smaller in magnitude than e, the size of the charge of the electron (1.6×10^{-19} coulomb). This is necessary if quarks are to combine together to give the correct electric charges for the observed particles, usually 0, +e, or −e. Only two types of quark are necessary to build protons and neutrons, the constituents of atomic nuclei. These are the up quark, with a charge of +2/3e, and the down quark, which has a charge of −1/3e. The proton consists of two up quarks and one down quark, which gives it a total charge of +e. The neutron, on the other hand, is built from one up quark and two down quarks, so that it has a net charge of zero. The other properties of the up and down quarks also add together to give the measured values for the proton and neutron. For example, the quarks have spins of 1/2. In order to form a proton or a neutron, which also have spin 1/2, the quarks must align in such a way that two of the three spins cancel each other, leaving a net value of 1/2.

Up and down quarks can also combine to form particles other than protons and neutrons. For example, the spins of the three quarks can be arranged so that they do not cancel. In this case they form short-lived resonance states, which have been given the name delta, or Δ. The deltas have spins of 3/2, and the up and down quarks combine in four possible configurations—uuu, uud, udd, and ddd—where u and d stand for up and down. The charges of these Δ states are +2e, +e, 0, and −e, respectively.

The up and down quarks can also combine with their antiquarks to form mesons. The pi-meson, or pion, which is the lightest meson and an important component of cosmic rays, exists in three forms: with charge e (or 1), with charge 0, and with charge −e (or −1). In the positive state an up quark combines with a down antiquark; a down quark together with an up antiquark compose the negative pion; and the neutral pion is a quantum mechanical mixture of two states—uuand dd, where the bar over the top of the letter indicates the antiquark.

Up and down are the lightest varieties of quarks. Somewhat heavier are a second pair of quarks, charm (c) and strange (s), with charges of +2/3e and −1/3e, respectively. A third, still heavier pair of quarks consists of top (or truth, t) and bottom (or beauty, b), again with charges of +2/3e and −1/3e, respectively. These heavier quarks and their antiquarks combine with up and down quarks and with each other to produce a range of hadrons, each of which is heavier than the basic proton and pion, which represent the lightest varieties of baryon and meson, respectively. For example, the particle called lambda (Λ) is a baryon built from u, d, and s quarks; thus, it is like the neutron but with a d quark replaced by an s-quark.

KARPAGAM ACADEMY OF HIGHER EDUCATION,COIMBATORE-21
DEPARTMENT OF PHYSICS
CLASS:I MSC PHYSICS
NUCLEAR PHYSICS (17PHP203)
MULIPLE CHOICE QUESTIONS

Unit - V

QUESTIONS	opt1	opt2	opt3	opt4	answer
Which operator is connected with spatial inversion	Parity	Charge conjugation	Time Reversal	All the above	Parity
The concept of a particle-antiparticle pair was originally developed by	Planck's	Einstein	J.J.Thomson	P.A.M.Dirac	P.A.M.Dirac
A symmetry scheme known as the ………………in which all the known particles and resonar	Eight fold way	Five fold way	Six fold way	None of these	Eight fold way
In SU(3), SU stands for	Single unitary	Special union	Special unitary	None of these	Special unitary
Isospin conservation law is obeyed by	All the four interactions	The EM,weak and strong only	Weak and strong only	Strong interaction only	Strong interaction only
Strangeness conservation law holds good in	Strong and electromagnetic interactio	All the four interactions	Weak and strong only	Weak only	Strong and electromagnetic interactions
Which conservation laws hold good in Strong and electromagnetic interactions	Strangeness	Parity	(a) & (b)	isospin	(a) & (b)
The process of changing every particle into its anti-particle is known as	Charge conjugation	Time reversal	Parity	All the above	Charge conjugation
Mesons have zero intrinsic spin but Baryons have	Half integral intrinsic spin	Full integral intrinsic spin	No any intrinsic spin	None of these	Half integral intrinsic spin
The particles of masses between π-meson mass and proton mass were called	Heavy mesons (k-meson)	Hyperons	Leptons	None of these	Heavy mesons (k-meson)
The particles of masses between proton and deuterium mass were called	k-meson	Hyperons	Leptons	None of these	Hyperons
Nucleons (protons and neutrons), Lamda particle(λ^0), sigma particle (∑), cascade particle (≡) a	Hyperons	Leptons	Baryons	None of these	Baryons
Baryons heavier than nucleons are called	Hyperons	Leptons	Lamda particle (λ^0)	None of these	Hyperons
A combination of a down quark (d) and an anti up quark u¯ called a	π^0 meson	A proton	π^- meson	Neutron	π^- meson
If π- was formed by a d quark and u quark the conservation law violated	Angular momentum and strangeness	Charge and baryon number	Linear momentum and energy	Charge and Lepton number	Charge and baryon number
An experiment is performed to search for evidence of the reaction pp→HK+K+. How many qu	Two	Three	Four	Six	Six
A neutral elementary particle whose isotopic spin projection is J_Z=+1/2 and Baryon charge B=	$\wedge^0$	Ξ^0	Σ^0	n	Ξ^0
∑^-→∧^0+π^- is forbidden by	Conservation of baryon number	Conservation of strangeness	Conservation of iso spin	Conservation of energy	Conservation of energy
The mode of decay for a neutron is observed n→p+e^- because the conservation laws does this	Energy and angular momentum	Energy and linear momentum	angular momentum and lepton number	Charge and baryon number	angular momentum and lepton number
The iso spin and the strangeness of Ω^- baryon are	1,-3	0,-3	1,3	0,3	0,-3
∧^0→p+k^- is forbidden as it violates	Charge conservation	Conservation of energy	Conservation of β-violation	Conservation of Le and Lμ	Conservation of β-violation
The quarks particle (u,d,s) possess fractional electric charges according to	2/3 e,-1/3 e,-1/3 e	-2/3 e,1/3 e,1/3 e	-1/3 e,2/3 e,1/3 e	1/3 e,2/3 e,-2/3 e	2/3 e,-1/3 e,-1/3 e
The baryon number of proton, the lepton number of proton, the baryon number of electron and	Zero,zero, one and zero	one,one,zero and one	one,zero,zero and one	Zero,one,one and zero	one,zero,zero and one
Except for mass, the properties of the muon most closely resemble the properties of the	Electron	Photon	Pions	Protons	Electron
If π^- was formed by a d quark and a u quark, the conservation law violated	Angular momentum and strangeness	Charge and baryon number	Linear momentum and energy	Charge and lepton number	Charge and baryon number
The reaction proceed by strong interaction $\pi^-+p\rightarrow\Xi^-+K^0+X$, identify X	π^+	K^0	p	γ	K^0
Quarks are elementary particles, first proposed by Gellmann to explain the discrepencies in	Structure of the neutron and its decay	Eight fold way in SU(3) symmetry gr	Structure of resonance particles discovered	Baryon structure	Structure of resonance particles discovered earlier
A conservation law that is not universal but applies only to certain kinds of interactions is con	lepton number	baryon number	spin	strangeness	strangeness
The particle decay $\wedge\rightarrow p+\pi^-$ must be a weak interaction because	The π^- is a lepton	The ∧ has spin zero	It does not conserve strangeness	No neutrino is produced in the decay	It does not conserve strangeness
The interaction that describes the forces among nucleons that hold nuclei together is	the strong nuclear (hadronic) interact	the electromagnetic interaction	the weak nuclear interaction	the gravitational interaction	the strong nuclear (hadronic) interaction
Current thought is that all matter is composed of is	six quarks	four quarks and four leptons	six leptons	six quarks and six leptons	six quarks and six leptons
Particles that participate in the strong nuclear interaction are called	neutrinos	hadrons	leptons	electrons	hadrons
Which of the following choices lists the four known types of forces in nature in order of decre	strong nuclear, electromagnetic, weal	electromagnetic, strong nuclear, weak	strong nuclear, gravitational, weak nuclear,	strong nuclear, weak nuclear, electromag	strong nuclear, electromagnetic, weak nuclear, gravitational
The conservation law violated by the reaction $p\rightarrow\pi^0+e^+$ is the conservation of	charge	energy	linear momentum	lepton number and baryon number	lepton number and baryon number
The concept of strangeness was introduced by	GellMann and Nishijima	Mayer	Bohr	None of these	GellMann and Nishijima
Meson production predominates at bombarding energy of	10MeV	few hundreds of MeV	Several hundred MeV	1MeV	Several hundred MeV
Which neutral unstable particle was named as lambda	Leptons	mesons	hyperons	hadrons	hyperons
The first hyperon was found in cosmic rays in 1947 by	Rochester and Butler	Gellmann and Nishijima	Mayer	J.J.Thomson	
The time reversal process is the creation of an electron-positron pair by the collision of	one photon	particles	waves	two photons	two photons
Isospin numbers are associated with hadrons but not with	leptons	mesons	hyperons	all of above	leptons
In a weak interaction involving change in strangeness of baryons or mesons, the change in stra	parity	charge	time	all the above	charge
Bosons are particles with intrinsic angular momentum equal to an	integral multiple of h	Half integral multiple of h	No any multiple of h	None of these	integral multiple of h
Fermions are all those particles in which the spin is	Full integral	No any spin	Half integral	None of these	Half integral
Strong interactions between elementary particles are responsible for the	decay of particles	total cross section as a function of en	fission	all the above	total cross section as a function of energy
The process of mutual annihilation of particles and anti-particles is an example of	nuclear interaction	coulomb repulsion	electromagnetic interaction	all the above	electromagnetic interaction
$\wedge^0+p=\Sigma^++n$ proceeds via	Strong interaction	Em interaction	Weak interaction	Cannot be predicted	Strong interaction
Which one of the following nuclear processes is forbidden?	$\bar{v}+p\rightarrow n+e^+$	$\pi^-\rightarrow e^-+v_e+\pi^0$	$\pi^-+p\rightarrow n+k^++k^-$	$\mu^-\rightarrow e^-+\bar{(v_e)}+v_\mu$	$\pi^-\rightarrow e^-+v_e+\pi^0$
$d+d=\alpha+\pi^0$ is forbidden due to violating the conservation of	Strangeness	Iso spin	Baryon number	Energy	Iso spin
$\pi^-+n=k^++\wedge^0$ is forbidden by violating	Conservation of strangeness	Conservation of iso spin	Conservation of energy	Conservation of charge and third compo	Conservation of charge and third component of iso spin
$k^++n=\Sigma^++\pi^0$ proceeds via	Strong interaction	Em interaction	Weak interaction	Cannot be predicted	Strong interaction
Consider the reactions ∑^+=n+e^++v_e k^+=π^++e^++e^-	Both of them proceed via the weak in	Both of them proceed via the strong i	Both of them are forbidden due to B violati	Both of them are forbidden due to Le an	Both of them proceed via the weak interaction
By considering the quark makeup of the various particles, deduce the identity of the unknown	proton	neutron	pions	omega	neutron
which of the following is allowed reaction	μ^+→e^++γ	π^+→μ^++v_μ	p+p→p+∑^++K^-	p→e^++ve	π^+→μ^++v_μ
Which of the following is forbidden	π^-+p→∑^-+k^+	π^-+p→k^-+k^++n	π^-+n→Ξ^-+k^++k^-	k^-+p→Ω^-+k^++k^0	π^-+n→Ξ^-+k^++k^-
K-mesons and η-mesons are allotted	Negative parity	Positive parity	Both type of parity	No parity	Negative parity
Which of the following reactions violates lepton number conservation?	e^++e^-→v+v¯	e^-+p→v+n	e^++n→p+v	μ^-→e^-+v+v¯	e^++n→p+v
Which one of the following nuclear processes is forbidden?	v¯+p→n+e^+	π^-→e^-+v_e+π^0	π^-+p→n+k^++k^-	μ^-→e^-+(v_e)¯+v_μ	π^-→e^-+v_e+π^0
Proton and neutron form an	isospin doublet	doublet	isospin	triplet	isospin doublet
A zero spin particle can exist in	two state	zero state	three state	All the above	two state
A spin particle can exist in	two state	zero state	three state	All the above	three state
The proton and neutron mass in terms of energy is about	0.5MeV	1BeV	several MeV	few MeV	1BeV
Massles Bosons are subject to	strong, weak and EM interaction	Weak interaction	Strong interaction	electromagnetic interaction only	electromagnetic interaction only
Pion was found to exist in	positive charged states	negative charged states	zero charged states	all three charged states	all three charged states
Mass of pion was estimated to be	$270m_e$	$270m_n$	0	1	$270m_e$
muon particle was found to have a life time of	10^{-6} sec	10^{-8} sec	10^{6} sec	50s	10^{-6} sec

Prepared by Dr. B. Janarthanan, Associate Professor, Department of Physics, KAHE

Reg No................

(17PHP203)

KARPAGAM ACADEMY OF HIGHER EDUCATION

COIMBATORE-21

DEPARTMENT OF PHYSICS

I M.Sc PHYSICS

Second Semester

I-Internal Examination (January2018)

NUCLEAR PHYSICS

Time:2 hours **Maximum:50 marks**

PART-A(20x1=20Marks)

Answer all questions

1. Nuclear exchange forces arise due to
   a)exchange of mesons b) exchange of charge c) exchange moments d) none of the above
2. Majorana force is due to
   a)exchange of space b) exchange of spin c) exchange of space and spin exchange of moments
3. Bartlet force is due to
   a)exchange of space b) exchange of spin c) exchange of space and spin d) exchange of moments
4. The hypothesis that nuclear forces possess an exchange character was put forward by
   a)Pauli b) Heisenberg c) Rutherford d) Max Plank
5. Instrument used to measure nuclear masses and their other properties is called
   a)Mass spectrograph b) nuclear spectrometer c) NMR spectrometer d) magnetic spectrometer
6. The existence of mesons were first observed in
   a)particle accelerators b) cosmic rays c) mass spectrometers d) none of the above
7. The binding energy per nucleuon is
   a)positive for all the nuclei b) negative for all the nuclei c) positive for nuclei of low mass number and negative for nuclei of higher mass number d) negative for nuclei of low mass number and positive for nuclei of higher mass number
8. Neutron was discovered by
   a)Chadwik b) Rutherford c) Bothe d) Jobliot
9. The spin of an alpha particle is
   a)1 b) 1/2 c) 3/2 d) 0
10. Alpha particle is of -----
    a)parity b) no parity c) odd even d) odd or even
11. According to Rutherford's scattering formula, the number of alpha-particles striking unit area of a fluorescent screen in front of a scatter is proportional to
    a)twice the thickness of the scatter b) inversely to the thickness of the scatter c) the thickness of the scatter d) none of the above
12. According to Gamow's theory of barrier penetration, the probability of penetration is ----- for particles of low mass
    a)large b) small c) does not depend on m d) zero
13. When a beta particle is emitted, the atomic mass
    a)increases by 2 b)increases by 1 c) decreases by 1 d) remains the same
14. During the beta emission an electron and neutrino is created with
    a)rest mass b) same as that of the electron c) 1836 times that of the electron zero d) 270 times that of the electron
15. The minimum energy required by the photon for pair production is

a)100 MeV b) 5 MeV c) 0.51 MeV d) 1.02 MeV

16. The intensity of the gamma-ray beam passed through thin sheet of thickness t reduces

a)linearly with t b) linearly with t^2
c) exponentially with t d) exponentially with t^2

17. The liquid drop model was suggested by

a)Bohr and Kalcker b) Fermi c) Rutherford d) Fermi

18. The average kinetic energy of nucleons inside nucleus is of the order of

a)1 MeV b) 10 MeV c) 100 MeV d).1 MeV

19. In ------ model, the nucleus is assumed to be containing a gas of protons and neutrons

a)liquid drop model b) alpha particle model
c) collective model d) Fermi gas model

20. The resemblance of the nucleus with a drop of liquid led to the suggestion of ----- model.

a)Fermi gas model b) collective model c) liquid drop model d) none of the above

PART-B (3 X 2 = 6 marks)

Answer all the questions

21. What is called semi-empirical mass formula?
22. State Pauli's hypothesis.
23. Compare water drop and nucleus.

PART-C (3 X 10 = 30 marks)

Answer all the questions briefly

24. a) State and explain the binding energy of the nucleus.

(OR)

b) Explain the ground state of deuterium.

25. a) Explain Geiger - Nuttall law.

(OR)

b) Discuss in detail Gamow teller transition.

26. a) Briefly discuss about the liquid drop model.

(OR)

b) Explain shell model of nucleus.

Reg. No.................................

[15PHP202]

KARPAGAM UNIVERSITY

Karpagam Academy of Higher Education
(Established Under Section 3 of UGC Act 1956)
COIMBATORE – 641 021
(For the candidates admitted from 2015 onwards)

M.Sc., DEGREE EXAMINATION, APRIL 2016

Second Semester

PHYSICS

NUCLEAR PHYSICS

Time: 3 hours Maximum : 60 marks

PART – A (20 x 1 = 20 Marks) (30 Minutes)
(Question Nos. 1 to 20 Online Examinations)

(Part - B & C 2 ½ Hours)

PART B (5 x 6 = 30 Marks)
Answer ALL the Questions

21. a) State and explain Semi empirical mass formula.

Or

b) Explain in detail about nature of nuclear forces. What is meant by nucleon-nucleon scattering?

22. a) Explain briefly about Gamow's theory of Alpha particles.

Or

b) Write notes on i) Selection rules in Beta process and ii) Internal Conversion.

23. a) Describe shell model for the explanation of magic numbers.

Or

b) Explain Collective model for quadrapole moments.

24. a) Write the principle and working of Nuclear reactors. Write about Isospin.

Or

b) Explain in detail about kinematics of Nuclear reaction.

25. a) Give brief explanation on classification of fundamental forces.

Or

b) Write notes on i) TCP theorem and ii) SU3 symmetry.

PART C (1 x 10 = 10 Marks)
(Compulsory)

26. Explain the different stages of nuclear reactions.

Reg. No................................

[14PHP304]

KARPAGAM UNIVERSITY

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M.Sc., DEGREE EXAMINATION, NOVEMBER 2015

Third Semester

PHYSICS

NUCLEAR PHYSICS AND PARTICLE PHYSICS

Time: 3 hours   Maximum : 60 marks

PART – A (20 x 1 = 20 Marks) (30 Minutes)
(Question Nos. 1 to 20 Online Examinations)

PART B (5 x 8 = 40 Marks) (2 ½ Hours)
Answer ALL the Questions

21. a. Discuss the ground state of Deuteron.

Or

b. Briefly explain the low energy nucleon-nucleon scattering.

22. a. Give an account on Gamow's theory of alpha decay.

Or

b. Explain in detail the Fermi's theory of Beta decay.

23. a. Explain how the shell model is successful in predicting the ground state spin of nuclei.

Or

b. Give a detailed account on optical model.

24. a. Discuss the continuum theory of nuclear reaction.

Or

b. Explain the different kinds of nuclear reactions.

25. a. Explain the classification of elementary particles and its properties in detail.

Or

b. Write a note on : i) CPT theorem ii) Eight fold way and super multiplets.
