



## PHYSICS

### BOOKS - HC VERMA PHYSICS (HINGLISH)

#### THE NUCLEOUS

#### Examples

1. Calculate the radius of  ${}^{70}\text{Ge}$



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2. Calculate the binding energy of an alpha particle from the following data:

$$\text{mass of } {}^1_1\text{H} \rightarrow m = 1.007825u$$

$$\text{mass of neutron} = 1.008665u$$

mass of  ${}^4_2\text{He}$   $\rightarrow m = 4.00260u$ .

Take  $1u = 931\text{MeVc}^{-2}$

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3. The atomic mass of  ${}^1_1\text{H}$  is  $1.00783u$ . Calculate the mass excess of hydrogen.

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4. The decay constant for the radioactive nuclide  ${}^{64}\text{Cu}$  is  $1.516 \times 10^{-5}\text{s}^{-1}$ . Find the activity of a sample containing  $1\mu\text{g}$  of  ${}^{64}\text{Cu}$ . Atomic weight of copper =  $63.5\text{gmo}^{-1}$ . Neglect the mass difference between the given radioisotope and normal copper.

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5. The half-life of a radioactive nuclide is 20 hours. What fraction of original activity will remain after 40 hours?

A.  $\frac{1}{4}$

B.  $\frac{1}{3}$

C.  $\frac{1}{2}$

D.  $\frac{1}{6}$

**Answer: A**



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6. The binding energy per nucleon is  $8.5\text{MeV}$  for  $A = 120$  and is  $7.6\text{MeV}$  for  $A = 240$  (see in figure). Suppose a nucleus with  $A = 240$  breaks into two nuclei of nearly equal mass numbers. Calculate the energy released in the process.



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7. Consider two deuterons moving towards each other with equal speeds in a deuteron gas. What should be their kinetic energies (when they are widely separated) so that the closest separation between them becomes  $2fm$ ? Assume that the nuclear force is not effective for separations greater than  $2fm$ . At what temperature will the deuterons have this kinetic energy on an average?

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## Worked Out Examples

1. Calculate the electric potential energy due to the electric repulsion between two nuclei of  $12C$  when they approach each other at the surface.

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2. Find the binding energy of  ${}_{26}^{56}\text{Fe}$ . Atomic mass of  ${}^{56}\text{Fe}$  is  $55.9349u$  and that of  ${}^1_1\text{H}$  is  $1.00783u$ . Mass of neutron =  $1.00867u$ .



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3. Find the kinetic energy of the  $\alpha$  - particle emitted in the decay

${}^{238}_{92}\text{Pu} \rightarrow {}^{234}_{90}\text{U} + \alpha$ . The atomic masses needed are as following:

${}^{238}\text{Pu}$   $238.04955u$

${}^{234}\text{U}$   $234.04095u$

${}^4\text{He}$   $4.002603u$ .

Neglect any recoil of the residual nucleus.



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4. Calculate the Q-value in the following decays:

(a)  ${}^{19}\text{O} \rightarrow {}^{19}\text{F} + e + \bar{\nu}$ .

(b)  ${}^{25}\text{Al} \rightarrow {}^{25}\text{Mg} + e^+ + \nu$ .

The atomic masses needed are as follows :

$^{19}\text{O}$  19.003576u

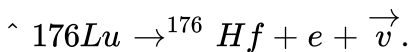
$^{19}\text{F}$  18.998403u

$^{25}\text{A}$  124.990432u

$^{25}\text{Mg}$  24.985839u

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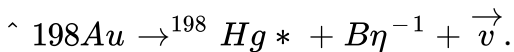
5. Find the maximum energy that a beta particle can have in the following decay



Atomic mass of  $^{176}\text{Lu}$  is 175.942694u and that of  $^{176}\text{Hf}$  is 175.941420u.

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6. Consider the beta decay



where  $^{198}\text{Hg}^*$  represents a mercury nucleus in an excited state at energy 1.088MeV above the ground state. What can be the maximum

kinetic energy of the electron emitted? The atomic mass of  $^{198}\text{Au}$  is  $197.968233u$  and that of  $^{198}\text{Hg}$  is  $197.966760u$ .

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7. The half-life of  $^{198}\text{Au}$  is  $2.7\text{days}$ . Calculate (a) the decay constant, (b) the average-life and (c) the activity of  $1.00\text{mg}$  of  $^{198}\text{Au}$ . Take atomic weight of  $^{198}\text{Au}$  to be  $198\text{gmol}^{-1}$ .

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8. A radioactive sample has  $6.0 \times 10^{18}$  active nuclei at a certain instant. How many of these nuclei will still be in the same active state after two half-lives?

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9. The activity of a radioactive sample falls from  $600 \text{ s}^{-1}$  to  $500 \text{ s}^{-1}$  in 40 minutes. Calculate its half-life.



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10. The number of  $^{238}\text{U}$  atoms in an ancient rock equals the number of  $^{206}\text{Pb}$  atoms. The half-life of decay of  $^{238}\text{U}$  is  $4.5 \times 10^9 \text{ y}$ . Estimate the age of the rock assuming that all the  $^{206}\text{Pb}$  atoms are formed from the decay of  $^{238}\text{U}$ .



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11. Equal masses of two samples of charcoal  $A$  and  $B$  are burnt separately and the resulting carbon dioxide are collected in two vessels. The radioactivity of  $^{14}\text{C}$  is measured for both the gas samples. The gas from the charcoal  $A$  gives 2100 counts per week and the gas from the charcoal  $B$  gives 2100 counts per week and the gas from the charcoal  $B$



gives 1400 counts per week. Find the age difference between the two samples. Half-life of  $^{14}\text{C} = 5730\text{y}$ .

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**12.** Suppose, the daughter nucleus in a nuclear decay is itself radioactive. Let  $\lambda_p$  and  $\lambda_d$  be the decay constants of the parent and the daughter nuclei. Also, let  $N_p$  and  $N_d$  be the number of parent and daughter nuclei at time  $t$ . Find the condition for which the number of daughter nuclei becomes constant.

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**13.** A radioactive sample decays with an average life of  $20\text{ms}$ . A capacitor of capacitance  $100\mu\text{F}$  is charged to some potential and then the plates are connected through a resistance  $R$ . What should be the value of  $R$  so that the ratio of the charge on the capacitor to the activity of the radioactive sample remains constant in time?

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14. A radioactive nucleus can decay by two different processes. The half-life for the first process is  $t_1$  and that for the second process is  $t_2$ . Show that the effective half-life  $t$  of the nucleus is given by

$$\frac{1}{t} = \frac{1}{t_1} + \frac{1}{t_2}.$$

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15. Calculate the energy released when three alpha particles combine to form a  ${}^{12}\text{C}$  nucleus. The atomic mass of  ${}^4_2\text{He}$  is  $4.002603u$ .

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### Short Answer

1. If neutrons exert only attractive force, why don't we have a nucleus containing neutrons alone?



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2. Consider two pairs of neutrons. In each pair, the separation between the neutrons is the same. Can the force between the neutrons have different magnitudes for the two pairs?



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3. A molecule of hydrogen contains two protons and two electrons. The nuclear force between these two protons is always neglected while discussing the behaviour of a hydrogen molecule. Why?



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4. Is it easier to take out a nucleon (a) from carbon or from iron (b) from iron or from lead?



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5. Suppose we have 12 protons and 12 neutrons. We can assemble them to form either a  $^{24}\text{Mg}$  nucleus or two  $^{12}\text{C}$  nuclei. In which of the two cases more energy will be liberated?

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6. What is the difference between cathode rays and beta rays? When the two are travelling in space, can you make out which is the cathode ray and which is the beta ray?

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7. If the nucleons of a nucleus are separated from each other, the total mass is increased. Where does this mass come from?

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8. In beta decay, an electron (or a positron) is emitted by a nucleus. Does the remaining atom get oppositely charged?



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9. When a boron nucleus ( ${}_{5}^{10}\text{B}$ ) is bombarded by a neutron, an  $\alpha$  - *partic*  $\leq$  is emitted. Which nucleus will be formed as a result?



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10. Does a nucleus lose mass when it suffers gamma decay?



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11. In a typical fission reaction, the nucleus is split into two middle-weight nuclei of unequal masses. Which of the two (heavier or lighter) has greater kinetic energy? Which one has greater linear momentum?



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12. If three helium nuclei combine to form a carbon nucleus, energy is liberated. Why can't helium nuclei combine on their own and minimise the energy?



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## Objective 1

1. The mass of a neutral carbon atom in ground state is

- A. exact  $12u$
- B. less than  $12u$
- C. more than  $12u$
- D. depends on the form of carbon such as graphite or charcoal.

**Answer: A**



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2. The mass number of a nucleus is equal to

- A. the number of neutrons in the nucleus
- B. the number of protons in the nucleus
- C. the number of nucleons in the nucleus
- D. none of them

**Answer: C**



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3. As compared to  $^{12}\text{C}$  atom,  $^{14}\text{C}$  atoms has

- A. two extra protons and two extra electrons
- B. two extra protons but no extra electron
- C. two extra neutrons and no extra electron

D. two extra neutrons and two extra electrons

**Answer: C**



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4. The mass number of a nucleus is equal to

A. always less than its atomic number

B. always more than its atomic number

C. equal to its atomic number

D. sometimes more than and sometimes equal to its atomic number.

**Answer: D**



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5. The graph of  $1n\left(\frac{R}{R_0}\right)$  versus  $1nA$  ( $R = \text{radius}$  of a nucleus and  $A = \text{its mass number}$ ) is

- A. a straight line
- B. a parabola
- C. an ellipse
- D. none of them

**Answer: A**



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6. Let  $F_{pp}$ ,  $F_{pn}$  and  $F_{nn}$  denote the magnitudes of the nuclear force by a proton on a proton, by a proton on a neutron and by a neutron on a neutron respectively. When the separation is  $1\text{fm}$ ,

- A.  $F_{pp} > F_{pn} = F_{nn}$
- B.  $F_{pp} = F_{pn} = F_{nn}$

$$C. F_p p > F_p n > F_n$$

$$D. F_p p < F_p n = F_n$$

**Answer: B**



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7. Let  $F_p p$ ,  $F_p n$  and  $F_n$  denote the magnitudes of the nuclear force by a proton on a proton, by a proton on a neutron and by a neutron on a neutron respectively. When the separation is  $1 fm$ ,

$$A. F_p p > F_p n = F_n$$

$$B. F_p p = F_p n = F_n$$

$$C. F_p p > F_p n > F_n$$

$$D. F_p p < F_p n = F_n$$

**Answer: D**



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8. Two protons are kept at a separation of  $10\text{nm}$ . Let  $F_n$  and  $F_e$  be the nuclear force and the electromagnetic force between them.

A.  $F_e = F_n$

B.  $F_e > F_n$

C.  $F_e < F_n$

D.  $F_e$  and  $F_n$  differ only slightly

**Answer: B**



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9. As the mass number  $A$  increases, the binding energy per nucleon in a nucleus.

A. increases

B. decreases

C. remains the same

D. varies in a way that depends on the actual value of  $A$

**Answer: D**



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**10.** Which of the following is a wrong description of binding energy of a nucleus?

- A. It is the energy required to break a nucleus into its constituent nucleons.
- B. It is the energy made available when free nucleons combine to form a nucleus.
- C. It is the sum of the rest mass energies of its nucleons minus the rest mass energy of the nucleus.
- D. It is the sum of the kinetic energy of all the nucleons in the nucleus.

**Answer: D**

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**11.** In one average-life,

- A. half the active nuclei decay
- B. less than half the active nuclei decay
- C. more than half the active nuclei decay
- D. all the nuclei decay

**Answer: C**

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**12.** In a radioactive decay, neither the atomic number nor the mass number changes. Which of the following particles is emitted in the decay?

- A. Proton
- B. Neutron
- C. Electron
- D. Photon

**Answer: D**

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**13.** During a negative beta decay,

- A. an atomic electron is ejected
- B. an electron which is already present within the nucleus is ejected
- C. a neutron in the nucleus decays emitting an electron
- D. a proton in the nucleus decays emitting an electron

**Answer: C**

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14. A freshly prepared radioactive source of half-life  $2h$  emits radiation of intensity which is 64 times the permissible safe level. The minimum time after which it would be possible to work safely with this source is

A.  $6h$

B.  $12h$

C.  $24h$

D.  $128h$

**Answer: B**



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15. The decay constant of a radioactive sample is  $\lambda$ . The half-life and the average-life of the sample are respectively

A.  $\frac{1}{\lambda}$  and  $\frac{\ln 2}{\lambda}$

B.  $\lambda(1n^2)$  and  $1/(\lambda)$

C.  $\lambda(1n^2)$  and  $1/(\lambda)$

D.  $\lambda/(1n^2)$  and  $1/\lambda$

**Answer: B**



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16. An  $\alpha$  particle is bombarded on  ${}^{14}\text{N}$ . As a result, a  ${}^{17}\text{O}$  nucleus is formed and a particle is emitted. This particle is a

A. neutron

B. proton

C. electron

D. positron

**Answer: B**



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17. Ten grams of  $^{57}\text{Co}$  kept in an open container beta-decays with a half-life of 270 days. The weight of the material inside the container after 540 days will be very nearly

A. 10 g

B. 5 g

C. 2.5 g

D. 1.25 g

**Answer: A**



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18. Free  $^{238}\text{U}$  nuclei kept in a train emit alpha particles. When the train is stationary and a uranium nucleus decays, a passenger measures that the separation between the alpha particle and the recoiling nucleus becomes  $x$  in time

After the decay, if a decay takes place when the train is moving at a speed  $v$

$v$

, the distance between the particles  $\leq$  and the recoil  $\leq$   $u$  at a time

$t'$  after the decay, as measured by the passenger will be

A.  $x + vt$

B.  $x - vt$

C.  $x$

D. depends on the direction of the train

**Answer: C**



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19. During a nuclear fission reaction,

A. a heavy nucleus breaks into two fragments by itself

B. a light nucleus bombarded by thermal neutrons breaks up

C. a heavy nucleus bombarded by thermal neutrons breaks up

D. two light nuclei combine to give a heavier nucleus and possibly other products

**Answer: C**



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## Objective 2

1. As the mass number  $A$  increases, which of the following quantities related to a nucleus do not change?

A. Mass

B. Volume

C. Density

D. Binding energy

**Answer: C**





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2. The heavier nuclei tend to have larger  $N/Z$  ratio because

- A. a neutron is heavier than a proton
- B. a neutron is an unstable particle
- C. a neutron does not exert electric repulsion
- D. Coulomb forces have longer range compared to the nuclear forces

**Answer: C::D**



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3. A free neutron decays to a proton but a free proton does not decay to a neutron. This is because

- A. neutron is a composite particle made of a proton and an electron  
whereas proton is a fundamental particle

B. neutron is an uncharged particle whereas proton is a charged particle

C. neutron has larger rest mass than the proton

D. weak forces can operate in a neutron but not in a proton.

**Answer: C**

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**4.** Consider a sample of a pure beta-active material

A. All the beta particles emitted have the same energy.

B. The beta particles originally exist inside the nucleus and are ejected at the time of beta decay.

C. The antineutrino emitted in a beta decay has zero mass and hence zero momentum.

D. The active nucleus changes to one of its isobars after the beta decay.

**Answer: D**



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5. In which of the following decays the atomic number decreases?

A.  $\alpha$  decay

B.  $\beta^+$  decay

C.  $\beta^-$  decay

D.  $\gamma$  decay

**Answer: D**



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6. In which of the following decays the element does not change?

A.  $\alpha$  decay

B.  $\beta^+$  decay

C.  $\beta^-$  decay

D.  $\gamma$  decay

**Answer: A::B**



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7. Magnetic field does not cause deflection in

A.  $\alpha$  rays

B. beta-plus rays

C. beta-minus rays

D. gamma rays

**Answer: D**



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**8. Which of the following are electromagnetic waves?**

- A.  $\alpha$  rays
- B. beta-plus rays
- C. beta-minus rays
- D. gamma rays

**Answer: D**



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**9. Two lithium nuclei in a lithium vapour at room temperature do not combine to form a carbon nucleus because**



- A. a lithium nucleus is more tightly bound than a carbon nucleus
- B. carbon nucleus is an unstable particle
- C. it is not energetically favourable
- D. Coulomb repulsion does not allow the nuclei to come very close.

**Answer: D**

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**10.** For nuclei with  $A > 100$ ,

- A. the binding energy of the nucleus decreases on an average as  $A$  increases
- B. the binding energy per nucleon decreases on an average as  $A$  increases
- C. if the nucleus breaks into two roughly equal parts, energy is released

D. if two nuclei fuse to form a bigger nucleus, energy is released

Answer: B::C



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## Exercises

1. Assume that the mass of a nucleus is approximately given by  $M = Am_p$  where  $A$  is the mass number. Estimate the density of matter in  $kgm^{-3}$  inside a nucleus.



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2. A neutron star has a density equal to that of the nuclear matter. Assuming the star to be spherical, find the radius of a neutron star whose mass is  $4.0 \times 10^{30}$  kg (twice the mass of the sun ).



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3. Calculate the mass of an  $\alpha$ -particle. Its binding energy is 28.2 MeV.

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4. How much energy is released in the following reaction:  ${}^7\text{Li} + p \rightarrow {}^4\text{He} + \alpha$ .  $A \rightarrow m_{\text{mass}} p$   ${}^7\text{Li} = 7.0160\text{u}$  and that of  ${}^4\text{He} = 4.0026\text{u}$ .

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5. Find the binding energy per nucleon of  ${}_{79}^{197}\text{Au}$  if its atomic mass is 196.96 u.

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6. (a) Calculate the energy released if  ${}^{238}\text{U}$  emits an  $\alpha$ -particle.  
(b) Calculate the energy to be supplied to  ${}^{238}\text{U}$

if  ${}^2\text{pro} \rightarrow \text{ns}$  and  ${}^2\text{utrons} \rightarrow \text{beemiedo} \neq \text{byo} \neq .$  Thealon

${}^{238}\text{U}$ ,  ${}^{234}\text{Th}$  and  ${}^4\text{He}$  are  $238.0508\text{u}$ ,  $234.04363\text{u}$  and  $4.00260\text{u}$  respectively.

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7. Find the energy liberated in the reaction



The masses of the nuclei are as follows.  ${}^{223}\text{Ra}$ ,  ${}^{209}\text{Pb}$ ,  ${}^{14}\text{C}$

$223.18\text{u}$ ,  $208.981\text{u}$ ,  $14.003\text{u}$ .

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8. Show that the minimum energy needed to separate a proton from a nucleus with  $Z$  protons and  $N$  neutrons is

$$\Delta E = (M_z - 1 + M_H - M_{Z,N}c^2)$$

where

$M_{Z,N}$  = mass of nucleus with  $Z$  protons and  $N$  neutrons

$M_H$  = mass of a hydrogen atom. this energy is known as proton-separation energy.

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9. Calculate the minimum energy needed to separate a neutron from a nucleus with  $Z$  protons and  $N$  neutrons in terms of the masses  $M_{Z,N}$ ,  $M_{Z,N-1}$  and the mass of the neutron.

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10.  $^{32}\text{P}$  beta-decays to  $^{32}\text{S}$ . Find the sum of the energy of the antineutrino and the kinetic energy of the  $\beta$ -particle. Neglect the recoil of the daughter nucleus. Atomic mass of  $^{32}\text{P} = 31.974u$  and that of  $^{32}\text{S} = 31.972u$ .

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11. A free neutron beta-decays to a proton with a half-life of 14 minutes .

(a) What is the decay constant ? (b) Find the energy liberated in the process.



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12. Complete the following decay schemes.

(a)  ${}_{88}^{226}\text{Ra} \rightarrow \alpha + (b) {}_8^{19}\text{O} \rightarrow {}_{19}^{9}\text{F} + (c) {}_{25}^{13}\text{Al} \rightarrow$   
 ${}_{12}^{25}\text{Mg} + \gamma$



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13. In the decay  ${}^{64}\text{Cu} \rightarrow {}^{64}\text{Ni} + e^- + \nu$ ,

the maximum kinetic energy of the electron is  $0.653 \text{ MeV}$  which was emitted in the form of a photon.

Use the formula applicable to photon.



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14. Potassium-40 can decay in three modes .It can decay by  $\beta^-$  -emission,  $\beta^+$  - emission or  $e^-$  capture. (a) Write the equations showing the decay of  ${}_{19}^{40}\text{K}$  to  ${}_{18}^{40}\text{Ar}$ ,  ${}_{20}^{40}\text{Ca}$  and  ${}_{18}^{40}\text{Ar}$ . The atomic masses of  ${}_{18}^{40}\text{Ar}$ ,  ${}_{19}^{40}\text{K}$  and  ${}_{20}^{40}\text{Ca}$  are 39.9624 u, 39.9640 u, and 39.9626 u respectively.

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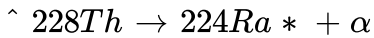
15. Lithium ( $Z=3$ ) has two stable isotopes  ${}^6\text{Li}$  and  ${}^7\text{Li}$ . When neutrons are bombarded on lithium sample electrons and  $\alpha$  -particles are ejected. Write down the nuclear processes taking place.

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16. The masses of  ${}^{11}\text{C}$  and  ${}^{11}\text{B}$  are respectively 11.0114 u and 11.0093 u. Find the maximum energy a positron can have in the  $\beta^+$  -decay of  ${}^{11}\text{C}$  to  ${}^{11}\text{B}$ .

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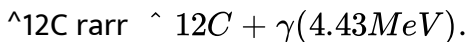
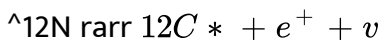
17.  ${}^{228}\text{Th}$  emits an alpha particle to reduce to  ${}^{224}\text{Ra}$ . Calculate the kinetic energy of the alpha particle emitted in the following decay:



Atomic mass of  ${}^{228}\text{Th}$  is  $228.028726\text{u}$ , that of  ${}^{224}\text{Ra}$  is  $224.020196\text{u}$  and that of  ${}^4_2\text{He}$  is  $4.00260\text{u}$ .

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18. Calculate the maximum kinetic energy of the beta particle emitted in the following decay scheme:



The atomic mass of  ${}^{12}\text{N}$  is  $12.018612\text{u}$ .

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19. The decay constant of  ${}_{80}^{197}\text{Hg}$  ( $e^-$   $\beta^-$   $\text{decay} \rightarrow {}_{79}^{197}\text{Au}$ ) is  $1.8 \times 10^{-4} \text{ s}^{-1}$ . (a) What is the half-life? (b) What is the average-life? (c) How much time will it take to convert 25% of mercury into gold?

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20. The half-life of  ${}^{198}\text{Au}$  is 2.7 days. (a) Find the activity of a sample containing 1.00 mg of  ${}^{198}\text{Au}$ . (b) What will be the activity after 7 days? Take the atomic weight of  ${}^{198}\text{Au}$  as 198 g mol $^{-1}$ .

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21. Radioactive  ${}^{138}\text{I}$  has a half-life of 8.0 days. A sample containing  ${}^{138}\text{I}$  has activity  $20 \mu\text{Ci}$  at  $t=0$ . (a) What is its activity at  $t=4.0$  days? (b) What is its decay constant at  $t=4.0$  days?

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22. The decay constant of  $^{238}\text{U}$  is  $4.9 \times 10^{-18} \text{ s}^{-1}$ .

- (a)  $\frac{dN}{dt} \geq -\lambda N$  if  $eof \ ^{238}\text{U}$ ? (b) What is the half-life of  $^{238}\text{U}$ ? (c) By what factor does the activity of a  $^{238}\text{U}$  sample decrease in  $9 \times 10^9$  years?

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23. A certain sample of a radioactive material decays at the rate of 500 per second at a certain time. The count rate falls to 200 per second after 50 minutes. (a) What is the decay constant of the sample? (b) What is its half-life?

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24. The count rate from a radioactive sample falls from  $4.0 \times 10^6$  per second to  $1.0 \times 10^6$  per second in 20 hours. What will be the count rate 100 hours after the beginning?

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25. The half-life of  $^{226}\text{Ra}$  is 1602 y. Calculate the activity of 0.1 g of  $\text{RaCl}_2$  in which all the radium is in the form of  $^{226}\text{Ra}$ . Taken atomic weight of Ra to be the 226  $\text{g mol}^{-1}$  and that of Cl to be 35.5  $\text{g mol}^{-1}$ .

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26. The half-life of a radioisotope is 10 h. Find the total number of disintegrations in the tenth hour measured from a time when the activity was 1 Ci.

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27. The selling rate of a radioactive isotope is decided by its activity. What will be the second-hand rate of a one month old  $^{32}\text{P}$  ( $t_{1/2} = 14.3$  days) source if it was originally purchased for 800 rupees?

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28.  $^{57}\text{Co}$  decays  $\rightarrow$   $^{57}\text{Fe}$  by  $\beta^+$ -emission. The resulting  $^{57}\text{Fe}$  is in its excited state and comes  $\rightarrow$  the ground state by emitting  $\gamma$ -rays. The half-life of  $\beta^+$ -decay is 270 days and  $t_{1/2}$  of the  $\gamma$ -emission is  $10^{-8}$  s. A sample of  $^{57}\text{Co}$  given  $5.0 \times 10^9$   $\gamma$  rays per second. How much time will elapse before the emission rate of  $\gamma$  rays drops to  $2.5 \times 10^9$  per second?

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29. Carbon ( $Z=6$ ) with mass number 11 decays to boron ( $Z=5$ ). (a) Is it a  $\beta^+$ -decay? (b) the half-life of the decay scheme is 20.3 minutes. How much time will elapse before a mixture of 90% carbon-11 and 10% boron-11 (by the number of atoms) converts itself into a mixture of 10% carbon-11 and 90% boron-11?

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30.  $4 \times 10^{23}$  tritium atoms are contained in a vessel. The half-life of decay of tritium nuclei is 12.3 y. Find (a) the activity of the sample, (b) the number of decays in the next 10 hours (c) the number of decays in the next 6.15 y.



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31. A point source emitting alpha particles is placed at a distance of 1 m from a counter which records any alpha particle falling on its  $1\text{cm}^2$  window. If the source contains  $6.0 \times 10^{16}$  active nuclei and the counter records a rate of 50000 counts//second, find the decay constant. Assume that the source emits alpha particles fall nearly normally on the window.



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32.  $^{238}\text{U}$  decays  $\rightarrow$   $^{206}\text{Pb}$  with a half-life of  $4.47 \times 10^9$  y. This happens in a number of steps. Can you just if  $y \sin g \leq i$

$^{238}\text{U}$  and 0.600 mg of  $^{206}\text{Pb}$ . Assuming that all the lead has come from uranium, find the life of the rock.

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33. When charcoal is prepared from a living tree, it shows a disintegration rate of 15.3 disintegrations of  $^{14}\text{C}$  per gram per minute. A sample of an ancient piece of charcoal shows  $^{14}\text{C}$  activity to be 12.3 disintegrations per gram per minute. How old is this sample? Half-life of  $^{14}\text{C}$  is 5730 y.

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34. Natural water contains a small amount of tritium ( $^1_3\text{H}$ ). This isotope  $\beta^-$  decays with a half-life of 12.5 years. A sample of water from a bottle of whisky, on return, has  $^1_3\text{H}$  radioactivity as compared to a recently purchased bottle marked '8 years old'. Estimate the time of that unsuccessful attempt.

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**35.** The count rate of nuclear radiation coming from a radioactive sample containing  $^{128}\text{I}$

varies with time as follows. Time  $t$  (min): 0 25 50 75 100 Count rate  $R$

( $10^9 \text{ s}^{-1}$ ): 30 16 8.0 3.8 2.0

(a) plot  $\ln(R_0/R)$  against  $t$ . (b) From the slope of the best straight line through the points, find the decay constant  $\lambda$ . (c) Calculate the half-life  $t_{1/2}$ .

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**36.** The half-life of  $^{40}\text{K}$  is  $1.30 \times 10^9$  y. A sample of 1.00g of pure KCl gives 160 counts  $\text{s}^{-1}$ . Calculate the relative abundance of  $^{40}\text{K}$  (the fraction of  $^{40}\text{K}$  present) in natural potassium.

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37.  ${}_{80}^{197}\text{Hg}$  decay  $\rightarrow$   ${}_{79}^{197}\text{Au}$  through electron capture with a decay constant of 0.257 per day. (a) What other particle or particles are emitted in the decay? (b) Assume that the electron is captured from the K shell. Use Moseley's law  $\sqrt{\nu} = a(Z - b)$  with a  $a = 4.95 \times 10^7 \text{ s}^{-1/2}$  and  $b=1$  to find the wavelength of the  $K_\alpha$  x-ray emitted following the electron capture.

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38. A radioactive isotope is being produced at a constant rate  $dN/dt = R$  in an experiment. The isotope has a half-life  $t_{1/2}$ . Show that after a time  $t \gg t_{1/2}$ , the number of active nuclei will become constant. Find the value of this constant.

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39. Consider the situation of the previous problem. Suppose the production of the radioactive isotope starts at  $t=0$ . Find the number of



active nuclei at time  $t$ .

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**40.** In an agriculture experiment, a solution containing 1 mole of a radioactive material ( $t_{1/2} = 14.3 \text{ days}$ ) was injected into the roots of a plant. The plant was allowed 70 hours to settle down and then activity was measured in its fruit. If the activity measured was  $1 \mu\text{Ci}$  what per cent of activity is transmitted from the root to the fruit in steady state?

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**41.** A vessel of volume  $125 \text{ cm}^3$  contains tritium ( $^3\text{H}, t_{1/2} = 12.3 \text{ y}$ ) at 500 kPa and 300 K. Calculate the activity of the gas.

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42.  ${}_{83}^{212}\text{Bi}$  decays either by  $\alpha$  or  $\beta$

–  $\alpha$  or  $\beta$

–  $\alpha$ . (a) Write the two equations showing the products of the decays.

$\alpha$  and  $\beta$

– decays are in the ratio 7/13. The overall half-life of  ${}^{212}\text{Bi}$  is one hour. If 1 g pure  ${}^{212}\text{Bi}$  is taken at 12.00 noon, what will be the composition of this sample at 1 p.m. the same day?



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43. A sample contains a mixture of  ${}^{110}\text{Ag}$  and  ${}^{108}\text{Ag}$  isotopes each having an activity of  $8.0 \times 10^8$  disintegrations per second.  ${}^{108}\text{Ag}$  is known to have a half-life of 100 days. The activity  $A$  is measured as a function of time and the following data are obtained.



(a) Plot  $\ln(A/A_0)$  versus time in days.

(b) Set  $\ln(A/A_0)$  versus time, the plot is a straight line.

(c) Use the half-life of  ${}^{108}\text{Ag}$  from this portion of the plot.

→ calculate the activity  $c$  or  $\text{respond} \in g \rightarrow \hat{110}\text{Ag}$  in the first 50 s .

(d) Plot  $\ln (A / A_0)$  versus time for  $\hat{110}\text{Ag}$  for the first 50 s. (e)  $f \in d$  the half - l if  $e$  of  $\hat{110}\text{Ag}$ .



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44. A human body excretes (removes by waste discharge, sweating, etc.) certain materials by a law similar to radioactivity. If technetium is injected in some form in 24 hours, a patient is given an injection containing  $\hat{99}\text{Tc}$ . This isotope is radioactive with a half - l if  $e$  of 6 hours. The activity of the sample is 6  $\mu\text{Ci}$ . How much time will elapse before the activity falls to 3  $\mu\text{Ci}$ ?



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45. A charged capacitor of capacitance  $C$  is discharged through a resistance  $R$ . A radioactive sample decays with an average-life  $\tau$ . Find the value of  $R$  for which the ratio of the electrostatic field energy stored in the capacitor to the activity of the radioactive sample remains constant in time.



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**46.** Radioactive isotopes are produced in a nuclear physics experiment at a constant rate  $dN/dt = R$ . An inductor of inductance  $100 \text{ mH}$ , a resistor of resistance  $100\Omega$  and a battery are connected to form a series circuit. The circuit is switched on at the instant the production of radioactive isotope starts. It is found that  $i/N$  remains constant in time where  $i$  is the current in the circuit at time  $t$  and  $N$  is the number of active nuclei at time  $t$ . Find the half-life of the isotope.



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**47.** Calculate the energy released by  $1\text{g}$  of natural uranium assuming  $200\text{MeV}$  is released in each fission event and that the fissionable isotope  $^{235}\text{U}$  has an abundance of  $0.7\%$  by weight in natural uranium.



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48. A uranium reactor develops thermal energy at a rate of 300 MW. Calculate the amount of  $^{235}\text{U}$  being consumed every second. Average energy released per fission is 200 MeV.



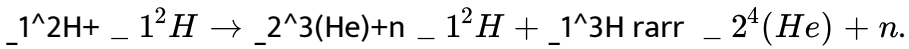
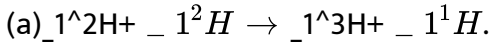
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49. A town has a population of 1 million. The average electric power needed per person is 300W. A reactor is to be designed to supply power to this town. The efficiency with which thermal power is converted into electric power is aimed at 25%. (a) Assuming 200 MeV of thermal energy to come from each fission event on an average, find the number of events on an average every day. (b) Assuming the fission to take place largely through  $^{235}\text{U}$ , at what rate will the amount of  $^{235}\text{U}$  decrease? Express your answer in kg per day. (c) Assuming that uranium is needed per month (30 days)?



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50. Calculate the Q-values of the following fusion reactions:



Atomic masses are  $m(\text{}^1_1\text{H}) = 2.014102 \text{ u}$ ,  $m(\text{}^2_1\text{H}) = 3.016049 \text{ u}$ ,  $m(\text{}^3_2\text{He}) = 3.016029 \text{ u}$ ,  $m(\text{}^4_2\text{He}) = 4.002603 \text{ u}$ .



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51. Consider the fusion in helium plasma. Find the temperature at which the average thermal energy  $1.5 \text{ kT}$  equals the Coulomb potential energy at  $2 \text{ fm}$ .



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52. Calculate the Q-values of the fusion reaction



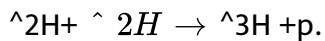
In such a fusion reaction, the reaction is typically favourable if  $Q > 0$ .

The atomic mass of  $\text{}^{16}_8\text{O}$  is  $15.994915 \text{ u}$  and that of  $\text{}^4_2\text{He}$  is  $4.0026 \text{ u}$ .



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53. Calculate the energy that can be obtained from 1 kg of water through the fusion reaction



Assume that  $1.5 \times 10^{-2} \%$  of natural water is heavy water  $\text{D}_2\text{O}$  (by number of molecules) and all the deuterium is used for fusion.



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