CHAPTER 27

Nuclei

1. At a specific instant emission of radioactive compound is deflected in a magnetic field. The compound can emit

(i) electrons (ii) protons

(iii) He^{2+} (iv) neutrons

The emission at instant can be **[2002]**

(a) i, ii, iii (b) i, ii, iii, iv

(c) iv (d) ii, iii

2. If N_0 is the original mass of the substance of half-life period $t_{1/2} = 5$ years, then the amount of substance left after 15 years is **[2002]**

(a) $N_0/8$ (b) $N_0/16$

(c) $N_0/2$ (d) $N_0/4$

3. When a U^{238} nucleus originally at rest, decays by emitting an alpha particle having a speed 'u', the recoil speed of the residual nucleus is **[2003]**

(a) $\frac{4u}{238}$ (b) $-\frac{4u}{234}$

(c) $\frac{4u}{234}$ (d) $-\frac{4u}{238}$

4. A radioactive sample at any instant has its disintegration rate 5000 disintegrations per minute. After 5 minutes, the rate is 1250 disintegrations per minute. Then, the decay constant (per minute) is **[2003]**

(a) 0.4 ln 2 (b) 0.2 ln 2

(c) 0.1 ln 2 (d) 0.8 ln 2

5. A nucleus with $Z = 92$ emits the following in a sequence:

$\alpha, \beta^-, \beta^- \alpha, \alpha, \alpha, \alpha, \alpha, \beta^-, \beta^-, \alpha, \beta^+, \beta^+, \alpha$

Then Z of the resulting nucleus is **[2003]**

(a) 76 (b) 78

(c) 82 (d) 74

6. Which of the following **cannot** be emitted by radioactive substances during their decay? **[2003]**

(a) Protons (b) Neutrinoes

(c) Helium nuclei (d) Electrons

7. In the nuclear fusion reaction

$$_1^2H + _1^3H \rightarrow _2^4He + n$$

given that the repulsive potential energy between the two nuclei is $\sim 7.7 \times 10^{-14}$ J, the temperature at which the gases must be heated to initiate the reaction is nearly

[Boltzmann's Constant $k = 1.38 \times 10^{-23}$ J/K] **[2003]**

(a) 10^7 K (b) 10^5 K

(c) 10^3 K (d) 10^9 K

8. A nucleus disintegrated into two nuclear parts which have their velocities in the ratio of 2 : 1. The ratio of their nuclear sizes will be **[2004]**

(a) $3^{1/2} : 1$ (b) $1 : 2^{1/3}$

(c) $2^{1/3} : 1$ (d) $1 : 3^{1/2}$

9. The binding energy per nucleon of deuteron $\left(_1^2H\right)$ and helium nucleus $\left(_2^4He\right)$ is 1.1 MeV and 7 MeV respectively. If two deuteron nuclei react to form a single helium nucleus, then the energy released is **[2004]**

(a) 23.6 MeV (b) 26.9 MeV

(c) 13.9 MeV (d) 19.2 MeV

10. If radius of the $_{13}^{27}Al$ nucleus is estimated to be 3.6 fermi then the radius of $_{52}^{125}Te$ nucleus be nearly **[2005]**

(a) 8 fermi (b) 6 fermi

(c) 5 fermi (d) 4 fermi

11. Starting with a sample of pure ^{66}Cu, $\frac{7}{8}$ of it decays into Zn in 15 minutes. The corresponding half life is **[2005]**

(a) 15 minutes (b) 10 minutes

(c) $7\frac{1}{2}$ minutes (d) 5 minutes

12. The intensity of gamma radiation from a given source is I. On passing through 36 mm of lead, it is reduced to $\frac{I}{8}$. The thickness of lead which will reduce the intensity to $\frac{I}{2}$ will be **[2005]**

(a) 9mm (b) 6mm
(c) 12mm (d) 18mm

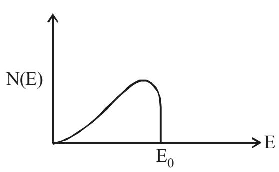
13. A nuclear transformation is denoted by $X(n, \alpha)\ {}^{7}_{3}\text{Li}$. Which of the following is the nucleus of element X? **[2005]**

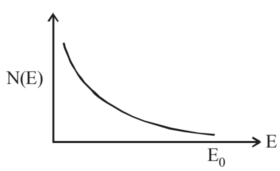
(a) ${}^{10}_{5}\text{B}$ (b) ${}^{12}\text{C}_6$
(c) ${}^{11}_{4}\text{Be}$ (d) ${}^{9}_{5}\text{B}$

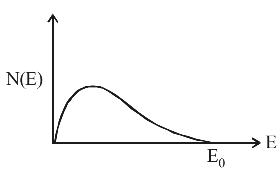
14. When ${}_3\text{Li}^7$ nuclei are bombarded by protons, and the resultant nuclei are ${}_4\text{Be}^8$, the emitted particles will be **[2006]**

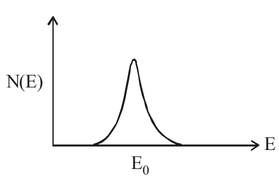
(a) alpha particles (b) beta particles
(c) gamma photons (d) neutrons

15. The energy spectrum of β-particles [number N(E) as a function of β-energy E] emitted from a radioactive source is **[2006]**

(a) 

(b) 

(c) 

(d) 

16. If the binding energy per nucleon in ${}^{7}_{3}\text{Li}$ and ${}^{4}_{2}\text{He}$ nuclei are 5.60 MeV and 7.06 MeV respectively, then in the reaction

$$p + {}^{7}_{3}\text{Li} \longrightarrow 2\ {}^{4}_{2}\text{He}$$

energy of proton must be **[2006]**

(a) 28.24 MeV (b) 17.28 MeV
(c) 1.46 MeV (d) 39.2 MeV

17. The 'rad' is the correct unit used to report the measurement of **[2006]**

(a) the ability of a beam of gamma ray photons to produce ions in a target
(b) the energy delivered by radiation to a target
(c) the biological effect of radiation
(d) the rate of decay of a radioactive source

18. If M_O is the mass of an oxygen isotope ${}_8\text{O}^{17}$, M_P and M_N are the masses of a proton and a neutron respectively, the nuclear binding energy of the isotope is **[2007]**

(a) $(M_O - 17M_N)c^2$
(b) $(M_O - 8M_P)c^2$
(c) $(M_O - 8M_P - 9M_N)c^2$
(d) $M_O c^2$

19. In gamma ray emission from a nucleus **[2007]**

(a) only the proton number changes
(b) both the neutron number and the proton number change
(c) there is no change in the proton number and the neutron number
(d) only the neutron number changes

20. The half-life period of a radio-active element X is same as the mean life time of another radio-active element Y. Initially they have the same number of atoms. Then **[2007]**

(a) X and Y decay at same rate always
(b) X will decay faster than Y
(c) Y will decay faster than X
(d) X and Y have same decay rate initially

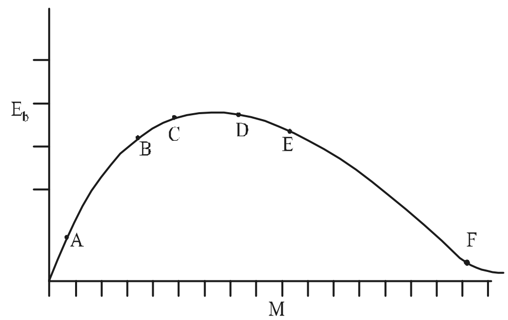
21. This question contains Statement-1 and statement-2. Of the four choices given after the statements, choose the one that best describes the two statements. **[2008]**

Statement-1:
Energy is released when heavy nuclei undergo fission or light nuclei undergo fusion and
Statement-2 :
For heavy nuclei, binding energy per nucleon

increases with increasing Z while for light nuclei it decreases with increasing Z.

(a) Statement-1 is false, Statement-2 is true
(b) Statement-1 is true, Statement-2 is true; Statement-2 is a correct explanation for Statement-1
(c) Statement-1 is true, Statement-2 is true; Statement-2 is not a correct explanation for Statement-1
(d) Statement-1 is true, Statement-2 is false

22.



The above is a plot of binding energy per nucleon E_b, against the nuclear mass M; A, B, C, D, E, F correspond to different nuclei. Consider four reactions : **[2009]**

(i) $A + B \to C + \varepsilon$
(ii) $C \to A + B + \varepsilon$
(iii) $D + E \to F + \varepsilon$ and
(iv) $F \to D + E + \varepsilon$,

where ε is the energy released? In which reactions is ε positive?

(a) (i) and (iii) (b) (ii) and (iv)
(c) (ii) and (iii) (d) (i) and (iv)

DIRECTIONS: Questions number 23-24 are based on the following paragraph.

A nucleus of mass $M + \Delta m$ is at rest and decays into two daughter nuclei of equal mass $\frac{M}{2}$ each. Speed of light is c.

23. The binding energy per nucleon for the parent nucleus is E_1 and that for the daughter nuclei is E_2. Then **[2010]**

(a) $E_2 = 2E_1$ (b) $E_1 > E_2$
(c) $E_2 > E_1$ (d) $E_1 = 2E_2$

24. The speed of daughter nuclei is **[2010]**

(a) $c\dfrac{\Delta m}{M + \Delta m}$ (b) $c\sqrt{\dfrac{2\Delta m}{M}}$
(c) $c\sqrt{\dfrac{\Delta m}{M}}$ (d) $c\sqrt{\dfrac{\Delta m}{M + \Delta m}}$

25. A radioactive nucleus (initial mass number A and atomic number Z emits 3 α - particles and 2 positrons. The ratio of number of neutrons to that of protons in the final nucleus will be **[2010]**

(a) $\dfrac{A-Z-8}{Z-4}$ (b) $\dfrac{A-Z-4}{Z-8}$
(c) $\dfrac{A-Z-12}{Z-4}$ (d) $\dfrac{A-Z-4}{Z-2}$

26. The half life of a radioactive substance is 20 minutes. The approximate time interval $(t_2 - t_1)$ between the time t_2 when $\frac{2}{3}$ of it had decayed and time t_1 when $\frac{1}{3}$ of it had decayed is : **[2011]**

(a) 14 min (b) 20 min
(c) 28 min (d) 7 min

27. After absorbing a slowly moving neutron of mass m_N (momentum ≈ 0) a nucleus of mass M breaks into two nuclei of masses m_1 and $5m_1$ ($6m_1 = M + m_N$) respectively. If the de Broglie wavelength of the nucleus with mass m_1 is λ, the de Broglie wavelength of the nucleus will be **[2011]**

(a) 5λ (b) $\lambda / 5$
(c) λ (d) 25λ

28. **Statement - 1 :** A nucleus having energy E_1 decays by β^- emission to daughter nucleus having energy E_2, but the β^- rays are emitted with a continuous energy spectrum having end point energy $E_1 - E_2$.

Statement - 2 : To conserve energy and momentum in β^- decay at least three particles must take part in the transformation. **[2011 RS]**

(a) Statement-1 is correct but statement-2 is not correct.

(b) Statement-1 and statement-2 both are correct and statement-2 is the correct explanation of statement-1.

(c) Statement-1 is correct, statement-2 is correct and statement-2 is not the correct explanation of statement-1

(d) Statement-1 is incorrect, statement-2 is correct.

29. Assume that a neutron breaks into a proton and an electron. The energy released during this process is : (mass of neutron = 1.6725×10^{-27} kg, mass of proton = 1.6725×10^{-27} kg, mass of electron = 9×10^{-31} kg). **[2012]**

(a) 0.51 MeV (b) 7.10 MeV
(c) 6.30 MeV (d) 5.4 MeV

30. Half-lives of two radioactive elements A and B are 20 minutes and 40 minutes, respectively. Initially, the samples have equal number of nuclei. After 80 minutes, the ratio of decayed number of A and B nuclei will be : **[2016]**

(a) 1 : 4 (b) 5 : 4
(c) 1 : 16 (d) 4 : 1

31. A radioactive nucleus A with a half life T, decays into a nucleus B. At t = 0, there is no nucleus B. At sometime t, the ratio of the number of B to that of A is 0.3. Then, t is given by **[2017]**

(a) $t = T \log(1.3)$ (b) $t = \dfrac{T}{\log(1.3)}$

(c) $t = T\dfrac{\log 2}{\log 1.3}$ (d) $t = T\dfrac{\log 1.3}{\log 2}$

Answer Key

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
(a)	(a)	(c)	(a)	(b)	(a)	(d)	(b)	(a)	(b)	(d)	(c)	(a)	(c)	(c)
16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
(b)	(c)	(c)	(c)	(c)	(d)	(d)	(c)	(b)	(b)	(b)	(c)	(b)	(a)	(b)
31														
(d)														

SOLUTIONS

1. (a) Charged particles are deflected in magnetic field.

2. (a) After every half-life, the mass of the substance reduces to half its initial value.

$$N_0 \xrightarrow{\text{5 years}} \frac{N_0}{2} \xrightarrow{\text{5 years}} \frac{N_0/2}{2}$$

$$= \frac{N_0}{4} \xrightarrow{\text{5years}} \frac{N_0/4}{2} = \frac{N_0}{8}$$

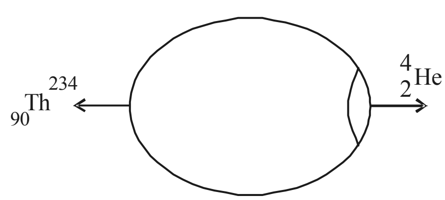
ALTERNATE SOLUTION

Number of half lives $n = \dfrac{15}{5} = 3$

We know that

$$N = N_0\left(\frac{1}{2}\right)^n = N_0\left(\frac{1}{2}\right)^3 = \frac{N_0}{8}$$

3. (c) Here, conservation of linear momentum can be applied



$$238 \times 0 = 4u + 234v$$

$$\therefore\ v = -\frac{4}{234}u$$

$$\therefore\ \text{speed} = |\vec{v}| = \frac{4}{234}u$$

4. **(a)** $\lambda = \frac{1}{t}\log_e \frac{A_o}{A} = \frac{1}{5}\log_e \frac{5000}{1250}$

$= \frac{2}{5}\log_e 2 = 0.4\log_e 2$

5. **(b)** The number of α-particles released = 8

Therefore the atomic number should decrease by 16

The number of β^--particles released = 4

Therefore the atomic number should increase by 4.

Also the number of β^+ particles released is 2, which should decrease the atomic number by 2.

Therefore the final atomic number

$= Z - 16 + 4 - 2 = Z - 14$

$= 92 - 14 = 78$

6. **(a)** The radioactive substances emit α-particles (Helium nucleus), β-particles (electrons) and neutrinoes.

7. **(d)** The average kinetic energy per molecule

$= \frac{3}{2}kT$

This kinetic energy should be able to provide the repulsive potential energy

$\therefore \frac{3}{2}kT = 7.7\times10^{-14}$

$\Rightarrow T = \frac{2\times7.7\times10^{-14}}{3\times1.38\times10^{-23}} = 3.7\times10^9$

8. **(b)** From conservation of momentum

$m_1v_1 = m_2v_2$

$\Rightarrow \left(\frac{m_1}{m_2}\right) = \left(\frac{v_2}{v_1}\right)$ given $\frac{v_1}{v_2} = 2$

$\Rightarrow \frac{m_1}{m_2} = \frac{1}{2} \Rightarrow \frac{r_1^3}{r_2^3} = \frac{1}{2} \Rightarrow \left(\frac{r_1}{r_2}\right) = \left(\frac{1}{2}\right)^{1/3}$

9. **(a)** The chemical reaction of process is

$2\,{}_1^2\text{H} \rightarrow {}_2^4\text{He}$

Energy released $= 4\times(7) - 4(1.1) = 23.6$ MeV

10. **(b)** $R = R_0(A)^{1/3}$

$\therefore \frac{R_1}{R_2} = \left(\frac{A_1}{A_2}\right)^{1/3} = \left(\frac{27}{125}\right)^{1/3} = \frac{3}{5}$

$R_2 = \frac{5}{3}\times3.6 = 6$ fermi

11. **(d)** $\frac{7}{8}$ of Cu decays in 15 minutes.

$\therefore$ Cu undecayed $= N = 1 - \frac{7}{8} = \frac{1}{8} = \left(\frac{1}{2}\right)^3$

$\therefore$ No. of half lifes = 3

$n = \frac{t}{T}$ or $3 = \frac{15}{T}$

$\Rightarrow T =$ half life period $= \frac{15}{3} = 5$ minutes

ALTERNATE SOLUTION

$N = N_0(1 - e^{-\lambda t})$

$\Rightarrow \frac{N_0 - N}{N_0} = e^{-\lambda t} \qquad \therefore \frac{1}{8} = e^{-\lambda t}$

$3\,\ell n\,2 = \lambda t$ or $\lambda = \frac{3\times0.693}{15} = 0.1386$

Half-life period,

$t_{1/2} = \frac{0.693}{\lambda} = \frac{0.693}{0.1386} = 5$ minutes

12. **(c)** Intensity $I = I_0.e^{-\mu d}$,

Applying logarithm on both sides,

$-\mu d = \log\left(\frac{I}{I_0}\right)$

$-\mu\times36 = \log\left(\frac{I/8}{I}\right)$ ....(i)

$-\mu\times d = \log\left(\frac{I/2}{I}\right)$ ....(ii)

Dividing (i) by (ii),

$\frac{36}{d} = \frac{\log\left(\frac{1}{8}\right)}{\log\left(\frac{1}{2}\right)} = \frac{3\log\left(\frac{1}{2}\right)}{\log\left(\frac{1}{2}\right)} = 3$ or $d = \frac{36}{3}$

$= 12$ mm

13. **(a)** $_ZX^A + {}_0n^1 \longrightarrow {}_3Li^7 + {}_2He^4$

On comparison,

$A = 7+4-1 = 10, z = 3+2-0 = 5$

It is boron $_5B^{10}$

14. **(c)** $^7_3\text{Li} + {}^1_1\text{p} \longrightarrow {}^8_4\text{Be} + {}^0_0\gamma$

15. **(c)** The range of energy of β-particles is from zero to some maximum value.

16. **(b)** Let E be the energy of proton, then

$E + 7\times 5.6 = 2\times[4\times 7.06]$

$\Rightarrow E = 56.48 - 39.2 = 17.28\text{MeV}$

17. **(c)** The risk posed to a human being by any radiation exposure depends partly upon the absorbed dose, the amount of energy absorbed per gram of tissue. Absorbed dose is expressed in rad. A rad is equal to 100 ergs of energy absorbed by 1 gram of tissue. The more modern, internationally adopted unit is the gray (named after the English medical physicist L. H. Gray); one gray equals 100 rad.

18. **(c)** Binding energy

$= [ZM_P + (A-Z)M_N - M]c^2$

$= [8M_P + (17-8)M_N - M]c^2$

$= [8M_P + 9M_N - M]c^2$

$= [8M_P + 9M_N - M_o]c^2$

19. **(c)** There is no change in the proton number and the neutron number as the γ-emission takes place as a result of excitation or de-excitation of nuclei. γ-rays have no charge or mass.

20. **(c)** According to question,

Half life of X, $T_{1/2} = \tau_{av}$, average life of Y

$\Rightarrow \dfrac{0.693}{\lambda_X} = \dfrac{1}{\lambda_Y}$

$\Rightarrow \lambda_X = (0.693).\lambda_Y$

$\therefore \lambda_X < \lambda_Y$.

Now, the rate of decay is given by

$-\left(\dfrac{dN}{dt}\right)_x = \lambda_X N_0$

$-\left(\dfrac{dN}{dt}\right)_y = \lambda_y N_0$

Y will decay faster than X.

21. **(d)** We know that energy is released when heavy nuclei undergo fission or light nuclei undergo fusion. Therefore statement (1) is correct.

The second statement is false because for heavy nuclei the binding energy per nucleon decreases with increasing Z and for light nuclei, B.E/nucleon increases with increasing Z.

22. **(d)** For $A + B \to C + \varepsilon$, ε is positive. This is because E_b for C is greater than the E_b for A and B.

Again for $\text{F} \to \text{D} + \text{E} + \varepsilon$, ε is positive. This is because E_b for D and E is greater than E_b for F.

23. **(c)** In nuclear fission, the binding energy per nucleon of daughter nuclei is always greater than the parent nucleus.

24. **(b)** By conservation of energy,

$(M+\Delta m)c^2 = \dfrac{2.M}{2}c^2 + \dfrac{1}{2}.\dfrac{2M}{2}v^2$,

where v is the speed of the daughter nuclei

$\Rightarrow \Delta mc^2 = \dfrac{M}{2}v^2$

$\therefore v = c\sqrt{\dfrac{2\Delta m}{M}}$

25. **(b)** As a result of emission of 1 α-particle, the mass number decreases by 4 units and atomic number decreases by 2 units. And by the emission of 1 positron the atomic number decreases by 1 unit but mass number remains constant.

∴ Mass number of final nucleus $= A - 12$

Atomic number of final nucleus $= Z - 8$

∴ Number of neutrons $= (A-12) - (Z-8)$

$= A - Z - 4$

Number of protons $= Z - 8$

∴ Required ratio $= \dfrac{A-Z-4}{Z-8}$

26. **(b)** Number of undecayed atom after time t_2 ;

$$\frac{N_0}{3} = N_0 e^{-\lambda t_2} \qquad ...(i)$$

Number of undecayed atom after time t_1;

$$\frac{2N_0}{3} = N_0 e^{-\lambda t_1} \qquad ...(ii)$$

From (i), $e^{-\lambda t_2} = \frac{1}{3}$

$$\Rightarrow -\lambda t_2 = \log_e\left(\frac{1}{3}\right) \qquad ...(iii)$$

From (ii) $- e^{-\lambda t_2} = \frac{2}{3}$

$$\Rightarrow -\lambda t_1 = \log_e\left(\frac{2}{3}\right) \qquad ...(iv)$$

Solving (iii) and (iv), we get

$t_2 - t_1 = 20$ min

27. **(c)** $p_i = 0$

$p_f = p_1 + p_2$

$p_i = p_f$

$0 = p_1 + p_2$

$p_1 = -p_2$

$\lambda_1 = \frac{h}{p_1}$

$\lambda_2 = \frac{h}{p_2}$

$|\lambda_1| = |\lambda_2|$

$\lambda_1 = \lambda_2 = \lambda.$

28. **(b)** **Statement-1:** Energy of β-particle from 0 to maximum so $E_1 - E_2$ is the continuous energy spectrum.

Statement-2: For energy conservation and momentum conservation at least three particles, daughter nucleus, β^{-1} and anti-neutron are required.

29. **(a)** ${}_0^1\text{n} \longrightarrow {}_1^1\text{H} + {}_{-1}\text{e}^0 + \bar{\nu} + Q$

The mass defect during the process

$$\Delta m = m_n - m_H - m_e = 1.6725 \times 10^{-27} - (1.6725 \times 10^{-27} + 9 \times 10^{-31}\text{kg})$$

$= -9 \times 10^{-31}$ kg

The energy released during the process

$E = \Delta mc^2$

$E = 9 \times 10^{-31} \times 9 \times 10^{16} = 81 \times 10^{-15}$ Joules

$$E = \frac{81 \times 10^{-15}}{1.6 \times 10^{-19}} = 0.511\text{MeV}$$

30. **(b)** For $A_{t_{1/2}} = 20$ min, t = 80 min, number of half lifes n = 4

$\therefore$ Nuclei remaining $= \frac{N_o}{2^4}$. Therefore nuclei decayed

$= N_0 - \frac{N_o}{2^4}$

For $B_{t_{1/2}} = 40$ min., t = 80 min, number of half lifes n = 2

$\therefore$ Nuclei remaining $= \frac{N_o}{2^2}$. Therefore nuclei decayed

$= N_0 - \frac{N_o}{2^2}$

$$\therefore \text{Required ratio} = \frac{\text{No} - \frac{\text{No}}{2^4}}{\text{No} - \frac{\text{No}}{2^2}} = \frac{1 - \frac{1}{16}}{1 - \frac{1}{4}} =$$

$$\frac{15}{16} \times \frac{4}{3} = \frac{5}{4}$$

31. **(d)** Let initially there are total N_0 number of nuclei

At time t $\quad \frac{N_B}{N_A} = 0.3$(given)

$\Rightarrow \quad N_B = 0.3 N_A$

$N_0 = N_A + N_B = N_A + 0.3 N_A$

$\therefore \quad N_A = \frac{N_0}{1.3}$

As we know $N_t = N_0 e - \lambda t$

or, $\frac{N_0}{1.3} = N_0 e - \lambda t$

$\frac{1}{1.3} = e^{-\lambda t} \qquad \Rightarrow \; ln(1.3) = \lambda t$

$$\text{or, } t = \frac{ln(1.3)}{\lambda} \;\Rightarrow\; t = \frac{ln(1.3)}{\frac{ln(2)}{T}} = \frac{ln(1.3)}{ln(2)} T$$