Name: ______________________

Class: ______________________

Due Date: ______________________

E.3 Radioactive Decay

Understandings

- Isotopes.
- Nuclear binding energy and mass defect.
- The variation of the binding energy per nucleon with nucleon number.
- The mass-energy equivalence as given by $E = mc^2$ in nuclear reactions.
- The existence of the strong nuclear force, a short-range, attractive force between nucleons.
- The random and spontaneous nature of radioactive decay.
- The changes in the state of the nucleus following alpha, beta, and gamma radioactive decay.
- The radioactive decay equations involving α, β^-, β^+, and γ.
- The existence of neutrinos ν and antineutrinos $\bar{\nu}$.
- The penetration and ionizing ability of alpha particles, beta particles, and gamma rays.
- The activity, count rate, and half-life in radioactive decay.
- The changes in activity and count rate during radioactive decay using integral values of half-life.
- The effect of background radiation of count rate.

Equations

$E = mc^2$

$\lambda = \frac{hc}{E}$

Additional HL Understandings

- The evidence for the strong nuclear force.
- The role of the ratio of neutrons to protons for the stability of nuclides.
- The approximate constancy of binding energy curve above a nucleon number of 60.
- The spectrum of alpha and gamma radiations provides evidence for discrete nuclear energy levels.
- The continuous spectrum of beta decay as evidence for the neutrino.
- The decay constant λ and the radioactive decay law as given by $N = N_0 e^{-\lambda t}$.
- The decay constant approximates the probability of decay in unit time only in the limit of sufficiently small λt.
- The activity as the rate of decay as given by $A = \lambda N = \lambda N_0 e^{-\lambda t}$.
- The relationship between half-life and the decay constant as given by $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$.

Additional HL Equations

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

$$A = \lambda N = \lambda N_0 e^{-\lambda t}$$

$$T_{\frac{1}{2}} = \frac{\ln}{\lambda}$$

The Evil Revealed in First US Nuclear Test: 74 Years Ago Over Bikini
https://www.activistpost.com/2020/06/the-evil-revealed-in-first-us-nuclear-test-74-years-ago-over-bikini.html

MIT Scientists: Nuclear Fusion Energy Could Be Closer Than Thought
https://oilprice.com/Alternative-Energy/Nuclear-Power/MIT-Scientists-Nuclear-Fusion-Energy-Could-Be-Closer-Than-Thought.html

The solutions can be found on the YouTube channel Go Physics Go:

https://www.youtube.com/@gophysicsgo/playlists

Use your favorite sources to answer the following questions

1. C: Define *isotope.*

2. C: *Isotopes* have the same ___________ properties but different ___________ properties.

3. C: Define *mass defect*. Units?

4. C: Which has more mass: two individual protons or two protons in the same nucleus?

5. C: Define *binding energy*. Units?

6. C: **Use a pencil and ruler!** Draw and label the *binding energy curve*. Label the horizontal and vertical axis. Label the most stable element.

7. C: Define *atomic mass unit*. Units?

8. C: Use the equation $\Delta E = \Delta m \times c^2$ to find the energy equivalent of 1 u in Joules and $\frac{\text{MeV}}{\text{c}^2}$.

9. E: Determine the binding energy per nucleon for a neutral carbon nucleus.

10.C: Define *transmutation.*

11.E: Consider an atom of $^{17}_{37}\text{Cl}$.

a. Determine the number of protons, neutrons, and electrons that make up this atom.

b. Determine the total mass of a Cl-37 nucleus based on the sum of its separate parts in kg and u.

c. The atomic mass of Cl-37 is approximately 36.965903 u. Subtract the mass of the electrons to determine the mass of a Cl-37 nucleus. Convert this to kg.

d. Find the difference between the mass of a single nucleus of Cl-37 and the sum of its parts in both kg and u. This is called the *mass defect*.

e. Convert this "mass defect" into the energy equivalent through $E = mc^2$.

f. Convert the resulting "energy defect" into binding energy per nucleon in $\frac{\text{MeV}}{\text{nucleon}}$.

12.C: What happens in nuclear decay if the *mass difference* is positive? Is nuclear decay possible?

13.C: What happens in nuclear decay if the *mass difference* is negative? Is nuclear decay possible?

14.C: Describe the *strong nuclear force*.

15.C: Define *random* and *spontaneous.*

16.C: *Radioactive decay* is both ___________ and ___________.

17.C: Define *alpha particle*. What is it made of? Charge?

18.C: What is the difference between an *alpha particle* and a *helium atom*?

19.E: Give two examples of *alpha decay*:

20.C: Define *neutrino*. What is it made of? Charge? Mass?

21.C: Define *anti-neutrino*. What is it made of? Charge? Mass?

22.C: Define *positron*. What is it made of? Charge? Mass?

23.C: Define *beta plus particle*. What is it made of? Charge? Mass?

24.C: What happens to a proton in a decaying nucleus during *beta plus decay*?

25.E: Give two examples of *beta plus decay*:

26.C: Define *beta minus particle*. What is it made of? Charge? Mass?

27.C: What is the difference between a *beta minus particle* and an *electron*?

28.C: What happens to a neutron in a decaying nucleus during *beta minus decay*?

29.E: Give two examples of *beta minus decay*:

30.C: Why was the neutrino postulated?

31.C: What is the charge and mass of an electron? What is the charge and mass of a neutrino ν?

32.C: Define *gamma ray*. What is it made of? Charge? Mass?

33.C: Why is it not correct to use the term *gamma particle*?

34.C: What is happening to an atom during *gamma decay*?

35.E: Give two examples of *gamma decay*: Gamma decay takes an excited and unstable atom and then makes it stable by releasing energy (as an electromagnetic wave) from the nucleus.

36.C: Define *ionization.*

37.C: Which particles have the most *ionizing ability* out of alpha particles, beta particles, and gamma rays?

38.C: Define *to penetrate.*

39.C: Define *penetrating power*. Which object can we use to stop an *alpha particle*? A *beta particle*? A *gamma ray*?

40.C: Define *half-life*. Units?

41.C: Define *activity*. Units? Use a **pencil and ruler!** Draw an activity vs. time graph for a radioactive/unstable element.

42.C: Complete the following sentences:

a. After one half-life the activity of the radioactive sample will decrease to ___________ of the original activity.
b. After two half-lives the activity of the radioactive sample will decrease to ___________ of the original activity.
c. After three half-lives the activity of the radioactive sample will decrease to ___________ of the original activity.
d. After four half-lives the activity of the radioactive sample will decrease to ___________ of the original activity.

43.C: Define *count rate*. Units?

44.C: Define *background radiation.*

Additional HL Content

45.C: Why do stable nuclei have more neutrons than protons?

46.C: What is the ratio of neutrons to protons for stable nuclei?

47.C: Circle the correct answer: Alpha particles leave the nucleus with *continuous/ discrete* energy levels.

48.C: Circle the correct answer: Beta minus particles leave the nucleus with *continuous/discrete* energy levels.

49.C: Circle the correct answer: Beta plus particles leave the nucleus with *continuous/discrete* energy levels.

50.C: Circle the correct answer: Gamma rays leave the nucleus with *continuous/ discrete* energy levels.

51.C: What is the meaning and units of the *decay constant* λ?

52.C: Describe and define the variables in the radioactive decay law equation $N(t) = N_0 e^{-\lambda}$.

53.C: What is the meaning and units for *activity A*? Describe and define the variables in the equation $A(t) = \lambda N(t) = \lambda N_0 e^{-\lambda t}$.

54.C: State the relationship between the half-life and the decay constant.

55.E: Cobalt-60 has a half-life of 5.271 years. Suppose that you have a sample of Co-60 which has a mass of 25.0 grams.

a. How many atoms will this sample contain?

b. What is the decay constant for this isotope (in decays per second)?

c. What will be the initial activity of this sample?

d. How many atoms of this sample will remain after 3.00 years?

e. What will be the activity of this sample after 3.00 years?

f. How many grams of radioactive Co-60 will remain after 3.00 years?

56. E: Strontium-90 has a half-life of 28.8 years. Suppose that you have a sample of Sr-90 which has a mass of 45.5 grams.

a. How many atoms will this sample initially contain?

b. What will be the decay constant of this isotope (in decays per second)?

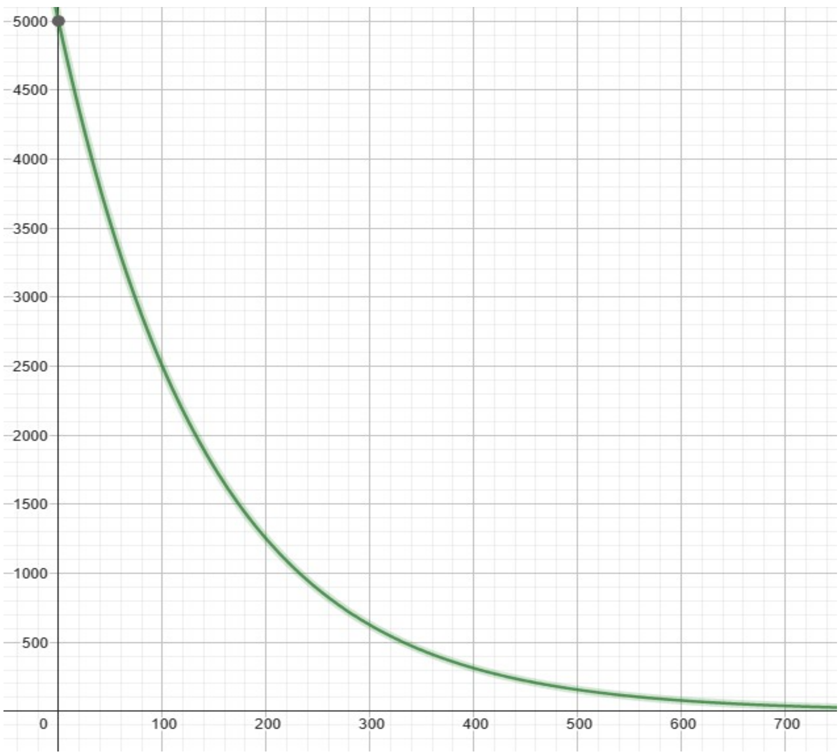
c. What will be the initial activity of this sample?

d. How many radioactive atoms of this isotope will remain after 100. years?

e. What will be the activity of this sample after 100. years?

f. How many grams of Sr-90 will remain after 100. years?

57.E: The graph below plots the activity of a radioactive sample as a function of time.



a. What is the half-life of this radioactive sample?

b. What is the decay constant of this isotope?

c. How many atoms were initially present in this sample?

d. What will be the activity of this sample after 10.0 minutes?

e. How long will it take for the activity of this sample to drop to 1.00% of its initial value?

f. How many radioactive atoms will remain after 10.0 minutes?

g. How many radioactive atoms will have decayed during the first 5.00 minutes?