

Course and Section \_\_\_\_\_

Names \_\_\_\_\_

Date \_\_\_\_\_

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## RADIOACTIVITY SIMULATION

### Introduction

In this simulation you will explore the features of an atom, what holds it together and what happens when it falls apart.

Input your answers into Blackboard.

### 1 – Preliminary questions

1. What is 1 amu in  $\text{MeV}/c^2$ ?

Consider aluminum  ${}_{13}^{27}\text{Al}$

2. What is the atomic number  $Z$  ?

3. What is the mass number  $A$  ?

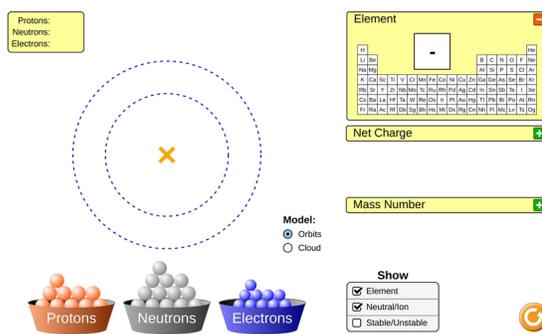
4. What is the neutron number  $N$  ?

5. What is the binding energy of oxygen  ${}_{8}^{16}\text{O}$  ( $\text{MeV}/c^2$ )

6. What is the binding energy of oxygen  ${}_{8}^{18}\text{O}$  ( $\text{MeV}/c^2$ )

### 2 – Building an atom

Open the simulation (<https://phet.colorado.edu/en/simulation/build-an-atom>) and select Symbol.



The simulation shows a blank space on which you can place protons, neutrons and electrons. Click the button *Stable/Unstable* to show stability. You can place as many protons, neutrons and electrons as you'd like.

Start with using only protons

7. How many protons does it take to create Boron?

8. Is this atom stable or unstable?

Start with using only protons

9. How many protons does it take to create lithium?

10. Is this atom stable or unstable?

Add one neutron at the time.

11. What is the minimum number of neutrons necessary for a stable atom of lithium?

12. Keep adding more and more neutrons, does the atom remain stable?

13. What is the max number of possible neutrons for the atom to remain stable?

Construct a Beryllium atom with  $Z = 4$  and  $N = 5$ .

14. What is the electric charge of this atom in terms of multiples of the fundamental Coulomb charge  $e = 1.602 \times 10^{-19}C$ ? i.e. an electron would have a charge of -1 in these units.

15. How many electrons are needed to make the atom electrically neutral?

16. How many electrons are in the inner orbit?

17. Can you put all of them in the inner orbit?

18. Is it possible to add all the available electrons into the atom?

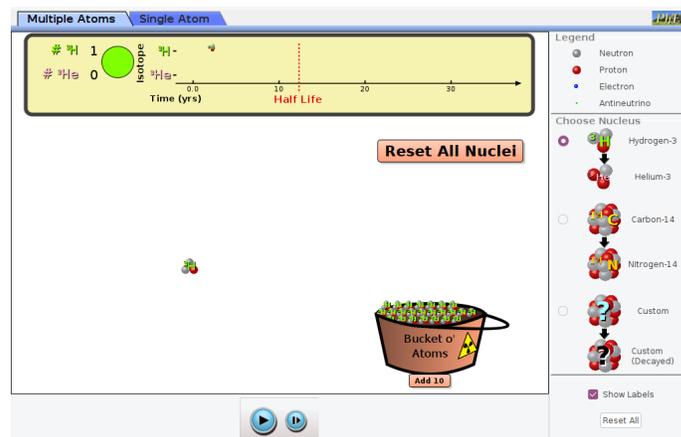
19. Does adding electrons change the stability of the atom?

20. Can you make a stable atom with at least one neutron such that  $Z$  is larger than  $N$ ?

21. If you answer yes to the previous question, what is the element?

### 3 – Beta Decay

Open the simulation (<https://phet.colorado.edu/en/simulation/legacy/beta-decay>) and run the java applet (you might have to download first it depending on your browser and OS)



In this simulation you can add radioactive nuclei to workspace and track their decays. The plot near the top displays in years. For every 1 second that passes in real life there is 1 year that passes in the simulation.

First press the pause button. Then click the button to add 10 particles of Hydrogen-3

22. How many neutrons are contained in Hydrogen-3?

Run the simulation and observe how the atoms decay. For one of the atoms:

23. What is the number of neutrons after the atom has decayed?

24. What is the number of protons after the atom has decayed?

25. Into which new isotope did Hydrogen decay?

26. Which process is responsible of the decay?

27. What is the blue particle which flies off the atom ?

Start over by pressing *Reset All* then press *Pause*. Add 20 hydrogen-3 particles.

Get out a stopwatch (your smart phone works well for this). You are going to press play and start your timer. For every decay you need to mark down the time it happens. You will have one less particle and the total number  $N$  will decrease over time. Track this for all particles until  $N = 0$ . You can record your data in a table similar to the one shown below. (Note: This may take you a few attempts to get right. It is useful to enter  $N=0.0001$  instead of  $N=0$ . Excel will have an issue finding a fit if you enter  $N=0$ ).

N	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Time																				

The number of atoms  $N$  at time  $t$  follows the empirical law:

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

where  $N_0$  is the initial number of atoms and  $\lambda$  is referred as the decay constant.

Plot  $N$  vs time and fit this line with an exponential.

28. What is the value of  $\lambda$  you extract from your fit?

29. Looking at your plot at about what time is there half of the atoms left?

The decay constant  $\lambda$  is related to the half-life  $t_{1/2}$  by

$$t_{1/2} = \frac{\ln(2)}{\lambda}$$

30. What is the half-life you get from your fit?

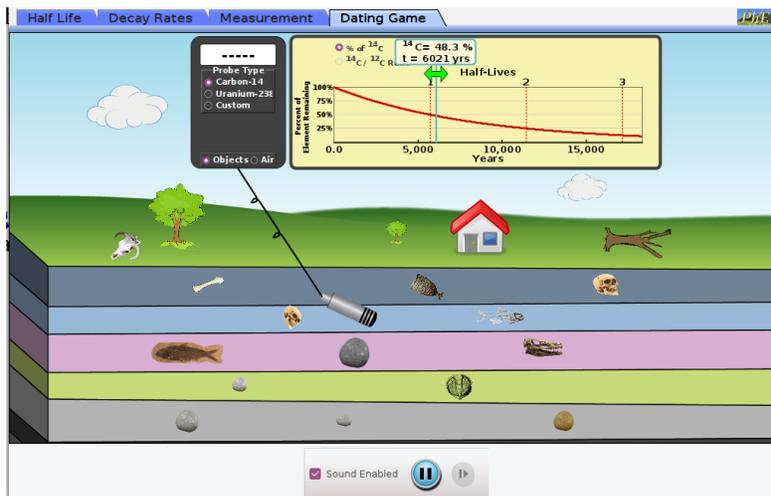
31. What is the percent difference between the value you read from your plot and the fitted value?

Looking at the simulation there is a line on the chart at the top to display the location of the half-life

32. Does your fitted value agree with this line?

## 4 – The Dating Game

Open the simulation (<https://phet.colorado.edu/en/simulation/radioactive-dating-game>) and run the java applet (you might have to download first it depending on your browser and OS). Select the fourth tab on the top *Dating Game*.



The simulation allows you to move a probe around in the screen to measure what percentage of a radioactive element remains in the sample. The simulation displays the percentage of the element remaining which is the fraction (of element remaining) times 100%.

$$\text{Percentage of Element Remaining} = \frac{N(t)}{N_0} \times 100\%$$

Using the definition of the decay rate  $\lambda = \ln(2)/t_{1/2}$  the age of the sample is:

$$\text{Age} = \frac{t_{1/2}}{\ln(2)} \times \ln(\text{Fraction of Element Remaining})$$

The equation above allows us to date organisms (with Carbon-14) and minerals (with Uranium-238). By using the probe and moving the green double arrow in the table, find the age of the objects below. (Before you can date a different object, to restart the simulation you must enter an estimate of the age).

33. What is the age of the house on the surface?
34. What is the age of the bone in the dark blue layer?
35. What is the age of the skull in the light blue layer?
36. Did the human die before or after the fish in the light blue layer?
37. What is the age of the rock in the center of the bottom layer?
38. What is the oldest object displayed in the simulation?