

## **Chapter 10: Debris and the Formation of the Solar System**

**Radioactive elements decay with a characteristic \_\_\_\_\_, the time it takes for half of a sample to decay.**

**alpha decay produces an alpha particle (essentially a \_\_\_\_\_ )**

**beta decay involves \_\_\_\_\_**

**$\beta^-$  decay is the conversion of a \_\_\_\_\_ into a \_\_\_\_\_**

**$\beta^+$  decay involves positron emission or electron \_\_\_\_\_**

**To age date a meteorite, you would preferably use a radioactive isotope that has a very long half-life, e.g.,**

**$^{40}\text{K}$  decays into  $^{40}\text{Ar}$  with a half-life of 1.3 Gyr**

**$^{238}\text{U}$  decays into  $^{206}\text{Pb}$  with a half-life of 4.5 Gyr**

**$^{87}\text{Rb}$  decays into  $^{87}\text{Sr}$  with a half-life of 49.7 Gyr**



# Periodic Table of Elements

| 1                                    | 2   | 3   | 4                                  | 5                                       | 6                                  | 7  | 8                                      | 9   | 10                                    | 11  | 12                                 | 13  | 14                                 | 15                                     | 16   | 17                                       | 18                                    |                                       |  |   |                                   |  |                                      |                                     |                                  |                                      |                                       |  |                                      |                                      |                                      |  |                                       |                                       |  |  |  |  |  |   |  |                                       |                                       |                                      |                                   |  |  |                                       |                                     |  |                                      |       |                                      |  |                                      |                                       |                                     |                                       |  |                                       |                                      |   |                                  |   |                                      |                                      |                                   |                                      |                                    |        |  |                                      |   |                                      |                                      |   |   |  |  |   |   |   |  |   |  |
|--------------------------------------|---|---|------------------------------------|---|------------------------------------|--|--|---|---------------------------------------|---|------------------------------------|---|------------------------------------|--|--|--|---------------------------------------|---------------------------------------|--|---|-----------------------------------|--|--------------------------------------|-------------------------------------|----------------------------------|--------------------------------------|---------------------------------------|--|--------------------------------------|--------------------------------------|--------------------------------------|--|---------------------------------------|---------------------------------------|--|--|--|--|--|---|--|---------------------------------------|---------------------------------------|--------------------------------------|-----------------------------------|--|--|---------------------------------------|-------------------------------------|--|--------------------------------------|-------|--------------------------------------|--|--------------------------------------|---------------------------------------|-------------------------------------|---------------------------------------|--|---------------------------------------|--------------------------------------|---|----------------------------------|---|--------------------------------------|--------------------------------------|-----------------------------------|--------------------------------------|------------------------------------|--------|--|--------------------------------------|---|--------------------------------------|--------------------------------------|---|---|--|--|---|---|---|--|---|--|
| 1<br><b>H</b><br>Hydrogen<br>1.00784 | Atomic #<br>Symbol<br>Name<br>Atomic Mass |   |                                    |   |                                    |  |  |   |                                       |   |                                    |   |                                    |  |  |  | 2<br><b>He</b><br>Helium<br>4.002602  |                                       |  |   |                                   |  |                                      |                                     |                                  |                                      |                                       |  |                                      |                                      |                                      |  |                                       |                                       |  |  |  |  |  |   |  |                                       |                                       |                                      |                                   |  |  |                                       |                                     |  |                                      |       |                                      |  |                                      |                                       |                                     |                                       |  |                                       |                                      |   |                                  |   |                                      |                                      |                                   |                                      |                                    |        |  |                                      |   |                                      |                                      |   |   |  |  |   |   |   |  |   |  |
| 3<br><b>Li</b><br>Lithium<br>6.941   | 4<br><b>Be</b><br>Beryllium<br>9.012182   | <b>C</b> Solid<br><b>Hg</b> Liquid<br><b>H</b> Gas<br><b>Rf</b> Unknown |                                    |   |                                    |  |  |   |                                       |   |                                    | <b>Metals</b><br>Alkali metals<br>Alkaline earth metals<br>Lanthanoids<br>Actinoids<br>Transition metals<br>Poor metals |                                    |  | <b>Nonmetals</b><br>Other nonmetals<br>Noble gases |  |                                       |                                       |  |   |                                   |  |                                      |                                     |                                  |                                      |                                       |  |                                      |                                      |                                      |  |                                       |                                       |  |  |  |  |  |   |  |                                       |                                       |                                      |                                   |  |  |                                       |                                     |  |                                      |       |                                      |  |                                      |                                       |                                     |                                       |  |                                       |                                      |   |                                  |   |                                      |                                      |                                   |                                      |                                    |        |  |                                      |   |                                      |                                      |   |   |  |  |   |   |   |  |   |  |
| 5<br><b>B</b><br>Boron<br>10.811     | 6<br><b>C</b><br>Carbon<br>12.0107        | 7<br><b>N</b><br>Nitrogen<br>14.0067                                    | 8<br><b>O</b><br>Oxygen<br>15.9991 | 9<br><b>F</b><br>Fluorine<br>18.9984032 | 10<br><b>Ne</b><br>Neon<br>20.1797 | 11<br><b>Na</b><br>Sodium<br>22.98976928 | 12<br><b>Mg</b><br>Magnesium<br>24.304 | 13<br><b>Al</b><br>Aluminum<br>26.9815386 | 14<br><b>Si</b><br>Silicon<br>28.0855 | 15<br><b>P</b><br>Phosphorus<br>30.973762 | 16<br><b>S</b><br>Sulfur<br>32.065 | 17<br><b>Cl</b><br>Chlorine<br>35.453   | 18<br><b>Ar</b><br>Argon<br>39.948 | 19<br><b>K</b><br>Potassium<br>39.0983 | 20<br><b>Ca</b><br>Calcium<br>40.078               | 21<br><b>Sc</b><br>Scandium<br>44.955912 | 22<br><b>Ti</b><br>Titanium<br>47.887 | 23<br><b>V</b><br>Vanadium<br>50.9415 | 24<br><b>Cr</b><br>Chromium<br>51.9961 | 25<br><b>Mn</b><br>Manganese<br>54.938045 | 26<br><b>Fe</b><br>Iron<br>55.845 | 27<br><b>Co</b><br>Cobalt<br>58.933195 | 28<br><b>Ni</b><br>Nickel<br>58.7074 | 29<br><b>Cu</b><br>Copper<br>63.546 | 30<br><b>Zn</b><br>Zinc<br>65.38 | 31<br><b>Ga</b><br>Gallium<br>69.723 | 32<br><b>Ge</b><br>Germanium<br>72.64 | 33<br><b>As</b><br>Arsenic<br>74.92160 | 34<br><b>Se</b><br>Selenium<br>78.96 | 35<br><b>Br</b><br>Bromine<br>79.904 | 36<br><b>Kr</b><br>Krypton<br>83.799 | 37<br><b>Rb</b><br>Rubidium<br>85.4678 | 38<br><b>Sr</b><br>Strontium<br>87.62 | 39<br><b>Y</b><br>Yttrium<br>88.90585 | 40<br><b>Zr</b><br>Zirconium<br>91.224 | 41<br><b>Nb</b><br>Niobium<br>92.90638 | 42<br><b>Mo</b><br>Molybdenum<br>95.90 | 43<br><b>Tc</b><br>Technetium<br>(97.9072) | 44<br><b>Ru</b><br>Ruthenium<br>101.07 | 45<br><b>Rh</b><br>Rhodium<br>102.90550 | 46<br><b>Pd</b><br>Palladium<br>106.42 | 47<br><b>Ag</b><br>Silver<br>107.8682 | 48<br><b>Cd</b><br>Cadmium<br>112.411 | 49<br><b>In</b><br>Indium<br>114.818 | 50<br><b>Sn</b><br>Tin<br>118.710 | 51<br><b>Sb</b><br>Antimony<br>121.760 | 52<br><b>Te</b><br>Tellurium<br>127.60 | 53<br><b>I</b><br>Iodine<br>126.90447 | 54<br><b>Xe</b><br>Xenon<br>131.293 | 55<br><b>Cs</b><br>Cesium<br>132.9054519 | 56<br><b>Ba</b><br>Barium<br>137.327 | 57-71 | 72<br><b>Hf</b><br>Hafnium<br>178.49 | 73<br><b>Ta</b><br>Tantalum<br>180.94788 | 74<br><b>W</b><br>Tungsten<br>183.87 | 75<br><b>Re</b><br>Rhenium<br>186.207 | 76<br><b>Os</b><br>Osmium<br>190.23 | 77<br><b>Ir</b><br>Iridium<br>192.222 | 78<br><b>Pt</b><br>Platinum<br>195.084 | 79<br><b>Au</b><br>Gold<br>196.966569 | 80<br><b>Hg</b><br>Mercury<br>200.59 | 81<br><b>Tl</b><br>Thallium<br>204.3833 | 82<br><b>Pb</b><br>Lead<br>207.2 | 83<br><b>Bi</b><br>Bismuth<br>208.98040 | 84<br><b>Po</b><br>Polonium<br>(209) | 85<br><b>At</b><br>Astatine<br>(210) | 86<br><b>Rn</b><br>Radon<br>(222) | 87<br><b>Fr</b><br>Francium<br>(223) | 88<br><b>Ra</b><br>Radium<br>(226) | 89-103 | 104<br><b>Rf</b><br>Rutherfordium<br>(261) | 105<br><b>Db</b><br>Dubnium<br>(262) | 106<br><b>Sg</b><br>Seaborgium<br>(266) | 107<br><b>Bh</b><br>Bohrium<br>(264) | 108<br><b>Hs</b><br>Hassium<br>(277) | 109<br><b>Mt</b><br>Meitnerium<br>(268) | 110<br><b>Ds</b><br>Darmstadtium<br>(271) | 111<br><b>Rg</b><br>Roentgenium<br>(272) | 112<br><b>Uub</b><br>Ununbium<br>(285) | 113<br><b>Uut</b><br>Ununtrium<br>(284) | 114<br><b>Uuq</b><br>Ununquadium<br>(289) | 115<br><b>Uup</b><br>Ununpentium<br>(288) | 116<br><b>Uuh</b><br>Ununhexium<br>(289) | 117<br><b>Uus</b><br>Ununseptium<br>(289) | 118<br><b>Uuo</b><br>Ununoctium<br>(294) |

For elements with no stable isotopes, the mass number of the isotope with the longest half-life is in parentheses.

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|   |   |  |   |  |                                       |  |   |   |  |   |                                      |  |   |   |
|---|---|--|---|--|---------------------------------------|--|---|---|--|---|--------------------------------------|--|---|---|
| 57<br><b>La</b><br>Lanthanum<br>138.90547 | 58<br><b>Ce</b><br>Cerium<br>140.12     | 59<br><b>Pr</b><br>Praseodymium<br>140.90768 | 60<br><b>Nd</b><br>Neodymium<br>144.242 | 61<br><b>Pm</b><br>Promethium<br>(145) | 62<br><b>Sm</b><br>Samarium<br>150.36 | 63<br><b>Eu</b><br>Europium<br>151.964 | 64<br><b>Gd</b><br>Gadolinium<br>157.25 | 65<br><b>Tb</b><br>Terbium<br>158.92535 | 66<br><b>Dy</b><br>Dysprosium<br>162.500 | 67<br><b>Ho</b><br>Holmium<br>164.93032 | 68<br><b>Er</b><br>Erbium<br>167.259 | 69<br><b>Tm</b><br>Thulium<br>168.93421  | 70<br><b>Yb</b><br>Ytterbium<br>173.054 | 71<br><b>Lu</b><br>Lutetium<br>174.967  |
| 88<br><b>Ac</b><br>Actinium<br>(227)      | 89<br><b>Th</b><br>Thorium<br>232.03806 | 90<br><b>Pa</b><br>Protactinium<br>231.03689 | 91<br><b>U</b><br>Uranium<br>238.02891  | 92<br><b>Np</b><br>Neptunium<br>(237)  | 93<br><b>Pu</b><br>Plutonium<br>(244) | 94<br><b>Am</b><br>Americium<br>(243)  | 95<br><b>Cm</b><br>Curium<br>(247)      | 96<br><b>Bk</b><br>Berkelium<br>(247)   | 97<br><b>Cf</b><br>Californium<br>(251)  | 98<br><b>Es</b><br>Einsteinium<br>(252) | 99<br><b>Fm</b><br>Fermium<br>(257)  | 100<br><b>Md</b><br>Mendelevium<br>(288) | 101<br><b>No</b><br>Nobelium<br>(289)   | 102<br><b>Lr</b><br>Lawrencium<br>(260) |



***We typically encounter the  $^{39}\text{K}$  and  $^{40}\text{Ar}$  isotopes for potassium and argon, or  $19\text{p}+20\text{n}$  and  $18\text{p}+22\text{n}$ , respectively.***

***How many protons and neutrons are in  $^{40}\text{K}$ ?***

***What is necessary for  $^{40}\text{K}$  to decay into  $^{40}\text{Ar}$ ?***

***We typically encounter the  $^{85}\text{Rb}$  and  $^{88}\text{Sr}$  isotopes for rubidium and strontium, or  $37\text{p}+48\text{n}$  and  $38\text{p}+50\text{n}$ , respectively.***

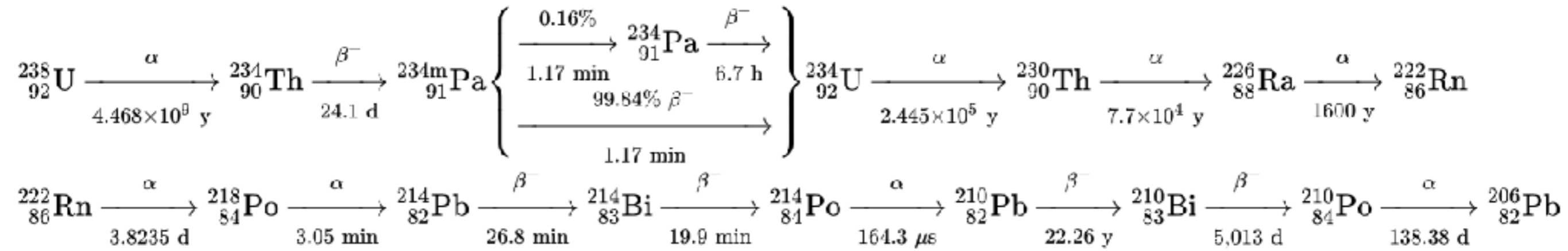
***How many protons and neutrons are in  $^{87}\text{Rb}$ ?***

***How many protons and neutrons are in  $^{87}\text{Sr}$ ?***

***What is necessary for  $^{87}\text{Rb}$  to decay into  $^{87}\text{Sr}$ ?***



**The chain of events is a bit more complicated for  $^{238}\text{U}$  to decay into  $^{206}\text{Pb}$ :**



**learning checkpoint: what kind of radioactive decay process is involved during the first step, when  $^{238}\text{U}$  decays to  $^{234}\text{Th}$ ?**

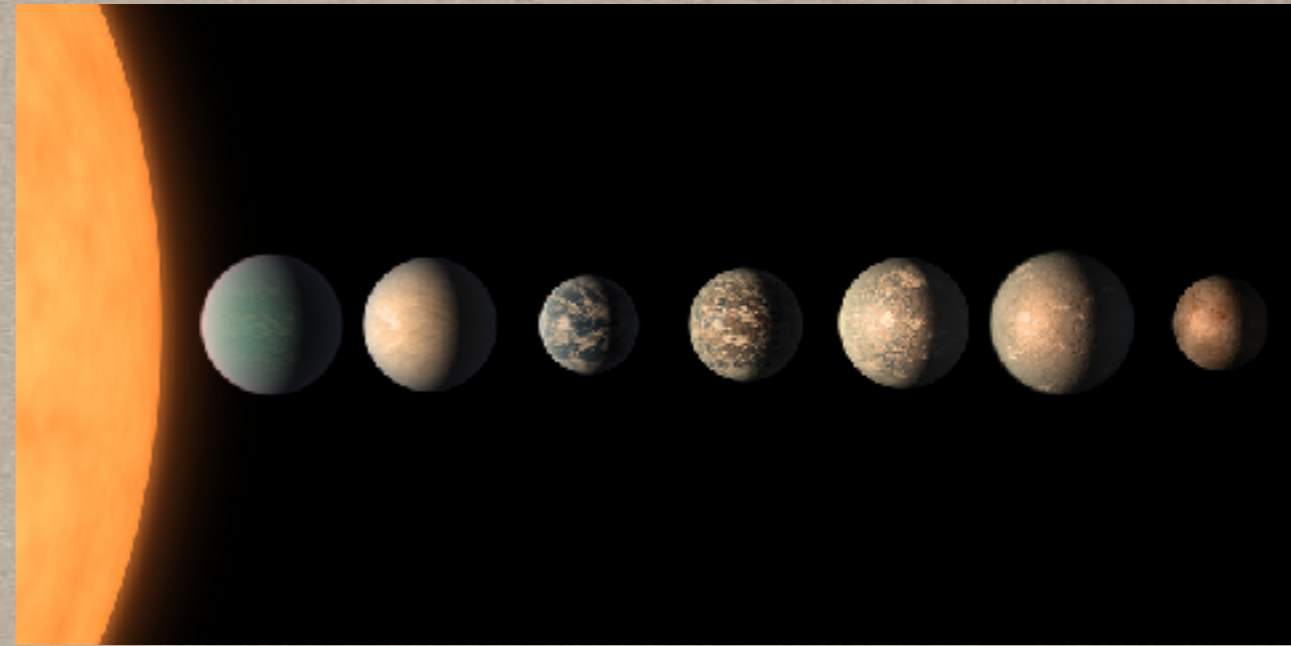


**The equation for the number of particles as a function of time is**

$$n(t) = n(t=0) 2^{-t/t_{\text{half}}}$$

**or**

$$t = t_{\text{half}} 3.322 \log_{10}[n(t=0)/n(t)].$$



**Q: Suppose that in the Trappist-1 planetary system you encounter an alien race that stupidly has decided to use third-lives instead of half-lives for expressing radioactive decay rates. What would be the equivalent mathematical expressions?**

$$n(t) =$$

$$t =$$



**Review Examples 1 & 2 on Pages 3 & 4**

**Q: Suppose we have rock that initially had no  $^{40}\text{Ar}$  but now has 40% as much  $^{40}\text{Ar}$  as  $^{40}\text{K}$ . How old is the rock?**

**You gotta love small-town local news: meteorite hits Wethersfield home in 1982.**

**In-class group work on radioactivity (see Chapter 10 Tutorials link)**