Radioactivity & Radioactive Dating

Number of protons in the nucleus tells us what element it is (atomic number).
Number of neutrons can vary. Atoms of an element that have different numbers of neutrons are called isotopes.
For example, isotopes of carbon can have 6, 7 or 8 neutrons:
C^{12} C^{13} C^{14}

Protons are positively charged and should repel each other; yet the nucleus does not immediately fly apart. The presence of neutrons has a stabilizing effect (the weak nuclear force is involved).
If the number of neutrons is not right, the nucleus is unstable.

Many isotopes are unstable - they fall apart or modify themselves to become stable. Isotopes that spontaneously "decay" are called radioactive.
Rate of radioactive decay does not depend on any external environmental factors (temperature, pressure, etc.).
The decay of a nucleus is a random event; you cannot predict when a given nucleus will undergo a decay.
However, the statistical rate of decay is constant for each type of isotope.

Amount of time for half a sample of radioactive isotopes to decay is called the "half-life".

If you wait for a length of time equal to the half-life, you'll have 1/2 of the isotopes you started with. If you wait another half-life, then you'll have 1/2 x 1/2 = 1/4 left.

Some common radioactive isotopes:

element	half-life
C^{14}	5730 years
P^{32}	14 days
K^{40}	1.3 billion years
U^{238}	4.5 billion years

Because half-life is independent of the environment, it is a very useful chronometer.

Example:
U^{238} decays into lead (Pb) with a half-life of 4.5 billions years.
Suppose a sample contains 2 kg of U^{238} and 6 kg of Pb.
Total amount of U+Pb is 8 kg.
Only 1/4 of the total is still U.
This means that 2 half-lives have gone by.
Therefore the sample is 9 billion years old.

The oldest meteorites and rocks from the lunar surface have been dated to about 4.5 G yrs using the decay of potassium-40 into argon-40 and uranium-238 to lead-206. This is the age of the Solar System.

Aside: Recall the composition of the Earth's present atmosphere:
Where did the 1.3 % argon come from?
Radioactive decay of K^{40} into Ar^{40} (half-life of 1.3 G yrs) puts argon into the Earth's atmosphere. Since it is a noble gas, it does not combine with other atoms and remains in the Earth's atmosphere. Argon is also present in Mars' atmosphere (about 1.5%).

Radioactive C^{14} Dating

Radioactive carbon C^{14} decays into N^{14} with a half-life of 5730 years.
Question: Can you use C^{14} to date the oldest rocks on Earth?

No.

C^{14} is only useful for dating objects less than 100,000 years old (and that is pushing it! 50,000 years is a reasonable practical limit).
In a time of ~100,000 years, about 18 half-lives have elapsed. The original amount of C^{14} in the sample has been reduced by $(1/2)^{18}$ = (1/2)(1/2)(1/2)(1/2)..... = ~ $4x10^{-6}$; only 4 millionths of the sample is left! This is too little to accurately work with.

C^{14} dating is useful for archeology, but not for astronomy (or geology).

Where does C^{14} come from?

Q: If C^{14} has such a “short” half-life, why isn’t it all gone?

It is constantly being created by nuclear reactions in the Earth’s atmosphere by cosmic rays.

“Cosmic rays” are particles (electrons, protons or nuclei) that travel with *very* high energy (nearly at the speed of light). They come from ***supernova*** explosions.

Billions of cosmic ray hit the Earth each second.
Most are stopped in the atmosphere. *Some* reach the ground....
About one particle strikes your body each second!
Cosmic rays can cause damage to your cell’s molecules. If that molecule is a DNA molecule, it can cause a mutation.