PHYSICS 1020

Homework set 15

24 March 1997

[**15.1**] Which force is stronger between two protons separated by 10^{-15}m (the size of a small nucleus), the electric or the strong force? What evidence do you have for your answer?
Answer:
At this distance, it is the strong force which is stronger; if it weren't, the nucleus would not hold together – the protons would be repelled by each other, and the nucleus would fly apart.

[**15.2**] Which force is stronger between two protons separated by 10^{-10}m (the size of an atom), the electric or the strong force? What evidence do you have for your answer?
Answer:
The strong force is much stronger than the electric force, but it has a short range, about 10^{-15}m. At a distance of 10^{-10}m, the strong force has a negligible effect. If the strong force were stronger than the electric force at this distance, nuclei would be much bigger than they are – there would be nuclei which are as big as atoms are now.

[**15.3**] How many protons and neutrons are there in these nuclei:

$$^{13}_{6}\mathrm{C}, \quad ^{56}_{26}\mathrm{Fe}, \quad ^{90}_{38}\mathrm{Sr}, \quad ^{3}_{1}\mathrm{H}\ ?$$

Answer:
In the symbols for nuclei, the superscript (the upper number) gives the "mass number" of the nucleus, i.e. the number of nucleons (= number of protons + number of neutrons), while the subscript (the lower number) gives the "atomic" number of the nucleus, i.e. the number of protons. Thus,
$^{13}_{6}$C (carbon-13) has 6 protons and 13 - 6 = 7 neutrons,
$^{56}_{26}$Fe (iron-56) has 26 protons and 56 - 26 = 30 neutrons,
$^{90}_{38}$Sr (strontium-90) has 38 protons and 90 - 38 = 52 neutrons,
and $^{3}_{1}$H (hydrogen-3 = tritium) has 1 proton and 3 - 2 = 2 neutrons.

[**15.7**] What do you suppose heated the water in a naturally heated hot spring?
Answer:
The radioactive decay of unstable nuclei in the Earth's interior causes warming of rock, which in turn heats the water.

[**15.12**] Use the periodic table to find the residual nucleus in each of the following:
beta decay of ^{3}H, beta decay of ^{90}Sr, alpha decay of ^{222}Rn.
Answer:
The decay reactions are:

$$^{3}_{1}\mathrm{H} \rightarrow\ ^{3}_{2}\mathrm{He} + \mathrm{e}^{-} + \bar{\nu}_{\mathrm{e}}$$

$$^{90}_{38}\mathrm{Sr} \rightarrow\ ^{90}_{39}\mathrm{Y} + \mathrm{e}^{-} + \bar{\nu}_{\mathrm{e}}$$

$$^{222}_{86}\mathrm{Rn} \rightarrow\ ^{218}_{84}\mathrm{Po} + \alpha$$

(note that $\alpha \equiv^{4}_{2}$ He, and ν_e is an "antineutrino".)

[**15.15**] Radon has a 4-day half-life. Starting with 1 gram of radon, how much will remain after 4 days? Starting with 10 radon atoms, how many will remain after 4 days? Is this a precise prediction? Why? If you have just one radon atom, will you still have it after 4 days?

Answer:

By definition, the probability of a nucleus having decayed after one half-life is equal to $1/2 = 50\%$. Therefore, the half-life is that time after which approximately half of a number of nuclei are expected to have decayed. Due to the random nature of the decay process, there are deviations from the expected fraction, due to random fluctuations. The smaller the number of nuclei that are being observed, the more important will be the relative deviations. The fraction of decayed nuclei will be very close to 1/2 if the number of nuclei was very large to start with, but for small numbers of nuclei, the deviations may be important. Starting with 1 gram of radon, we expect half a gram to remain after 4 days (= one half-life), and since one gram represents a very large number of radon nuclei ($\approx 3 \times 10^{21}$), it will be rather close to the expected amount. Starting with ten nuclei, we expect on the average five to have decayed after four days, but there is a significant probability that there will be a few more or less: the probability that exactly five nuclei decay is about 17%, for 6 it is about 14%, for one it is about 3.4%, and the probability that none has decayed is still about 0.7%.

[**15.18**] Can we carbon-date ordinary rocks? Why? Can we carbon-date objects that are a million years old? Why?

Answer:

Since ordinary rocks do not contain any formerly living material, they cannot be carbon-dated. Objects that are a million years old, even if they originate from formerly living things, cannot be carbon-dated either; the reason is that after this long time, nearly all of the carbon-14 has decayed, and so these objects do not contain enough of it to be measurable.