Physics 102 – Spring 2011 – Recitation module 6

Quantum dice:

In quantum mechanics we cannot predict the oucome of a single measurement, but rather we can predict the correct average of many measurements.

Break up into groups of 2. One person (the experimenter) tosses a single die 48 times keeping track of the values on the top face of the die for each toss. The other person (the oracle) moves where they cannot see the die being thrown and predicts/attempts to predict the value seen for each of the 48 throws of the die and records the predicted value.

How often does the oracle correctly predict what the experimentalist measures?

How often would you expect the oracle to get it right just due to random luck?

How much variation is there among all the oracles in your section in terms of the number of correct predictions they make?

What is the average value of all the measurements made by the experimentalist?

What would you expect to find for the average value of all the measurments?

Quantum dice 2:

In groups of two, one person tosses two dice sequentially 48 times. When the first die comes up as a “1” or a “2”, the other person records the value of the second die.

Compare the distribution and average value of the measurments with what was observed in the first quantum dice exercise. Discuss this comparison? Does it make sense to you?

Now repeat the experiment above. However, this time instead of throwing the second die, take as your measured value the number on the bottom face of the first die (remember only take those where the first die comes up a “1” or “2”). Compare the distibution and average of your measurements with what you saw earlier.

Can you explain the difference you see?

How might this situation be similar to "quantum entanglement"?

Some types of atomic nuclei are unstable and naturally decay to more stable nuclei. In the process of doing this, they emit a particle in a manner that is very similar to how an atom emits a photon when the electron makes a transition from one orbital to another in the Bohr model or in the quantum mechanical solution to the hydrogen atom. In this case, however, the energy change between the different quantum (nuclear configurations) states is much larger than in the atomic case. With such large energy differences, these unstable nuclei can emit photons (as in the atomic case, but more energetic – in the gamma ray region of the electromagnetic spectrum), electrons (historically called beta particles in this context), or alpha particles (two protons and two neutrons). Generically, we refer to these naturally unstable nuclei as radioactive substances. The particles that are emitted are generically referred to as "radiation". Radiation from radioactive substances is unavoidable. Small amounts of radioactive substances permiate your environment. That said, it is important to minimize your contact with radioactive substances where possible. Radiation such as alpha, beta, and gamma rays are potentially harmful to living things because the particles can ionize (rip apart) the molecules in biological tissue, killing cells and causing long-term DNA damage. If the radiation dose is high enough, the cell damage can kill the living thing. If the damage is not that severe, the DNA damage can lead to cancer and/or birth defects many years later.

Only particles that are electrically charged can cause ionization damage as they pass through tissue. The larger the electrical charge of the ionizing radiation, the heavier is the ionizing damage and the shorter the range of the radiation in the material. Gamma rays pass harmlessly through materials until they interact with the electric field of a nucleus in the material and convert into an electron and a positron (an anti-electron, just like an electron except the charge is positive) – a process called pair production. A beam of gamma rays will pass through an object with a (well-understood and calculable) fraction of them interacting and undergoing pair production at different locations in the object. Where those interactions happen, the energy of the converted gamma ray is given to the electron-positron pair, which then damage the tissue through the ionization process typical of charged particles.

Gamma rays can pass through living tissue and other materials and are generally only stopped by something like a thick layer of lead.

Beta particles (electrons or positrons) can be stopped by the outer layers of skin.

Alpha particles can be stopped by a sheet of paper.

Different types of naturally radioactive nuclei exhibit differing degrees of instability. Some types of nuclei are prone to decay quickly, while others are more stable and only decay slowly. This characteristic is quantified by what is known as the "half-life" of the substance. The half-life is the amount of time it takes for half the nuclei in a given sample to decay away (the decay of each nucleus means the emission of a particle).

If you are handling a radioactive substance, what are some things to consider that will minimize the danger to you?

How does the dentist protect you while taking detal x-rays of your mouth?

Suppose you accidently ingested a glass of water contaminated with a radioactive substance. Would you rather that substance be an alpha emitter, beta emitter, or gamma emitter? (Assume equal half-lives for the three different options.) Why do you say this?

Suppose you had to sleep the night next to that radioactive water, which type of emitter would you hope for? Why?

Carbon-14 is an "isotope" (what is this?) of carbon with 6 protons and 8 neutrons. It has a half-life of approximatly 5000 years. Suppose you have a sample of Carbon-14 with 100,000 atoms and tuck it away securely in a glass vial. How many atoms would you expect to be in that sample after 15,000 years?

How well can the speed of an electron in the hydrogen atom be measured (in principle)? Hint: The size of the hydrogen atom is approximately 10^{-10} meters.