PHYSICS 1020

Homework set 14

17 March 1997

[**14.4**] Explain, in terms of inertia, why the electron does nearly all the moving in a hydrogen atom.

Answer:

The electron's mass is much smaller (by a factor of 1836) than that of the proton, so its inertia is correspondingly smaller. The center of mass is therefore approximately the center of the proton. The motion of electron and proton around their joint center of mass is thus essentially motion of the electron.

A more down-to-earth formulation is that the electron, due to its smaller inertia, can be more easily set in motion than the more massive proton. Since the forces they exert on each other are the same in magnitude, the electron is subject to a larger acceleration than the proton.

[**14.5**] Assuming that the string's length in Fig. 14.5 is 2 m, could the string vibrate in a standing wave whose wavelength is 2.1 m? 1.9m? 0.5m? Explain.

Answer:

Since the string is fixed at both ends, its ends must be nodes of the standing wave motion. Thus, only those standing waves are allowed for which the length of the string is an integer multiple of a half wavelength. Therefore the possible wavelengths are: (2 times stringlength / n, with n=1,2,3,...) = 4m, 2m, 4/3 m, 1m, 4/5 m, 2/3 m, 4/7 m, 1/2 m,...

Thus, 0.5 meters is an allowed wavelength.

[**14.7**] If a very accurate measurement of an atom's mass could be made in an excited state and in its ground state, would any difference be found? (Hint: remember $E = mc^2$). What happens to an atom's mass when it emits a photon?

Answer:

Since an excited atom has more energy than an atom in its ground state, its mass is bigger (because of the mass-energy equivalence). When an atom emits a photon, it loses energy, and therefore its mass decreases.

[**14.8**] In Fig. 14.11, which quantum jump creates the higher frequency photon, n=4 to n=3 or n=4 to n=2? Which of the two photons has the longer wavelength?

Answer:

The energy of the photon emitted in a quantum jump (a transition from one state to another) equals the difference between the energies of the two states. Since this difference is larger between the states n=4 and n=2, it is this transition which creates the photon with the higher energy. Because of $E = h \cdot f$, this also means higher frequency. The wavelength is related to the frequency by $f \cdot \lambda = c$, and therefore higher frequency means shorter wavelength; the photon with the longer wavelength is the one with the lower frequency, i.e. with lower energy, which is the photon emitted in the transition from n=4 to n=3.

[14.12] How would it affect you if Planck's constant were 1 Js instead of 6.6×10^{-34}Js?
Answer:
The main effect would be that quantum uncertainties (due to the uncertainty relation) would be large enough to be observable at the macroscopic level; Newtonian physics would not be a good approximation.

[14.13] If Planck's constant were smaller than it is, would this affect the size of atoms? How? What would happen if Planck's constant were zero?
Answer:
A smaller Planck's constant would allow atoms to be smaller, due to smaller quantum uncertainties. If Planck's constant were zero, there would be no quantum effects – everything would be continuous and smooth, fully predictable in the Newtonian sense, but – we might not exist to be bored by this.

[14.15] One everyday example in which a measurement disturbs the measured object is the measurement of the temperature of a pan of water using a thermometer. How does this disturb the temperature? Is this a quantum effect?
Answer:
In order for the thermometer to show the temperature of the water in the pan, it has to achieve thermal equilibrium with the water whose temperature is to be measured. To do this it has to absorb heat from the water in the pan (if it was colder to start with), or it has to dump some of its thermal energy into the water. As a consequence, the temperature of the water will change due to the process of measuring it. The change will be smaller, the smaller the heat capacity of the thermometer compared to that of the water. This is not a quantum effect – it can be fully explained by Newtonian physics – classical thermodynamics.

[14.16] Making estimates: The electron in a ground-state hydrogen atom is confined by electric forces to remain in a sphere measuring roughly 10^{-10}m in diameter. An electron's mass is about 10^{-30}kg. Use these data along with the uncertainty relation to estimate the speed of this electron. (Hint: In the ground state, the electron's speed should be roughly equal to the uncertainty in the speed, in other words, $v \approx \Delta v$. See the discussion at the end of sect.14.3.) What fraction of the speed of light is this?
Answer:
Using the uncertainty relation in the form

$$\Delta x \times \Delta p \approx h,$$

we find that

$$v \approx \Delta v \approx \frac{h}{\Delta x \cdot m} = \frac{6.6 \times 10^{-34}\,\text{Js}}{10^{-10}\text{m} \cdot 10^{-30}\text{kg}} = 6.6 \times 10^{6}\text{m/s}$$

In terms of the speed of light, this is

$$\frac{v}{c} = \frac{6.6 \times 10^{6}}{3 \times 10^{8}} \approx 2.2 \times 10^{-2}.$$

So the electron moves at approximately 2% of the speed of light.

[14.18] Your friend flips a coin but covers it up so that neither of you can tell whether it is heads or tails. What odds (probability) would be fair to put on heads? Suppose he uncovers it and you see that it is tails; what odds should you now assign to heads? Does this sudden shift in the probabilities have anything to do with quantum theory?

Answer:

For an unbiased coin, the probability of tossing heads is $0.5 = 50\%$. After the uncovering, knowing that the outcome was tails, the odds on tails change to 0, as a consequence of the new knowledge that you have acquired, not because of a quantum effect.

[14.23] List several general ways in which Nature is non-Newtonian and several specific phenomena (such as radioactive decay) that are non-Newtonian. In what ways is Nature Newtonian? List several specific phenomena (such as the fall of a rock) that are, to a very good approximation, Newtonian.

Answer:

Non-Newtonian features are, e.g.: radioactive decay, the quantum states of an atom, line spectra of atoms and molecules, the wave nature of particles (electrons, protons, atoms....), the particle nature of light, quantum jumps,...
Newtonian phenomena are: the path of a football, hitting a baseball with a bat, forces on macroscopic objects, the motions of the planets, the collision of two cars, the swinging of a pendulum,.... all macroscopic forces and motions.