Phys 340: FINAL EXAMINATION

Thursday, 24th April, 2003;   3.30-6.00 pm

This exam will last 2 hrs and 30 mins. You should answer 4 questions from section A (these should take roughly 15 mins each), and 2 questions from section B (these will take roughly 45 mins each).

SECTION A

A(1): Describe what is meant by the *retrograde* motion of a planet in the sky, and *why* it is that we see this retrograde motion (according to modern physics). You can use pictures to help explain these ideas.

Now, with reference to the Platonic theory of Forms, explain briefly what Plato and Eudoxus thought about these motions.

A(2): Describe Newton's rotating bucket experiment, and explain its role in distinguishing between absolute and relative motions. Explain what one sees if the bucket is not rotating, then what happens if it has been rotating for a long time without changing its angular velocity, and then finally, what happens if one then suddenly stops the bucket from rotating.

A(3): An electron moving at a velocity of 1 metre per second has a quantum mechanical wavelength of roughly 0.7 mm. What would be the wavelength of the matter wave for an atom of Fe moving at the same velocity, given that its mass is about 100,000 times greater?

A(4): One illustration of Newton's mechanics, which Newton himself discusses in the *Scholium*, concerns a pair of globes that are joined together by a cord. Newton imagines a situation where these globes (and the cord) are in an "immense vacuum", i.e. they are the only material objects existing in all of space. In this case, when the globes cannot have any motions relative to external objects, how could one tell whether the globes are at rest, or rotating about their common centre of mass? Explain your answer, by reference to Newton's laws of motion.

Also- what would happen if one cut the cord? What would be the difference between the case where the globes rotate around each other, and where they do not?

A(5): Huyghens argued that no conclusion based on experiments could be considered a proof. Nevertheless he argued that some experiments could be more convincing than others for a theory. Explain in what context you think that experiments can make a theory very probably correct, and why.

A(6): One often sees pictures of atoms in which the electrons are shown as "clouds" around the nucleus. Explain briefly what these clouds are supposed to represent. What is the relationship between the wave-function $\psi(\mathbf{r})$ of an electron at position $\mathbf{r}$, and the density of the cloud at position $\mathbf{r}$?

Now explain briefly why the electrons on 2 different atoms want to overlap as they approach each other, and how this leads to chemical bonds. You should relate this to the uncertainty principle (usually written as $\Delta\mathbf{r} = h/\delta\mathbf{p}$, relating the spread $\Delta\mathbf{r}$ and $\Delta\mathbf{p}$, in the values of $\mathbf{r}$, $\mathbf{p}$ respectively).

A(7) Can you explain how you would test to see whether space is Euclidean or not? You should describe one experiment you would do to test the idea, and explain what criterion you would use to decide the answer.

A(8) After Bohr developed his quantum model for the atom in 1912- the so-called 'old quantum theory'- it was only a matter of time before the correct quantum theory was found in 1925. Experiment played little role in this period. However a number of crucial experimental facts were important in the development of the old quantum theory of Planck, Einstein, and Bohr. Give 2 examples of these experimental facts.

SECTION B

B(1): Francis Bacon believed in something that has been called "Immaculate Perception", viz.,

'all depends on keeping the eye steadily fixed upon the facts of nature and so receiving their images simply as they are.'

Such 'theory-free' observation is considered by many to be the foundation of scientific work.

(i) Galileo observed the satellites of Jupiter using a refracting telescope. Show using a simple diagram how the light passes through such a telescope, and is received by the eye.

(ii) Within less than a century of Galileo's work there were 2 competing explanations for light propagation through lenses. One was the particle theory of Newton, and the other was the wave theory of Huyghens. Draw a diagram of how light passes from air into glass (assume a flat interface between the two), and then explain how it is that each theory is supposed to explain what happens.

(iii) If one tries to very strongly magnify the image produced by a telescope, one sees that the edges of objects appear to be blurred. This is a diffraction effect. If the aperture of Galileo's telescope was 5 cm., and the wavelength of the light was 0.5 μm (ie., 5×10^{-7} m), then by roughly how large an angle does this diffraction take place?

(iv) In view of these various features of the operation of the telescope, explain which features of telescopic observations are, in your opinion, to be considered theory-free, and which features are not. What matters here is the development of the arguments you use to reach your conclusions, as well as whether your conclusions make sense.

B(2): Plato argued that the physical objects we are aware of are not the most basic or primitive objects that exist- that more basic "forms", not accessible via our senses, were more fundamental.

(i) Give briefly what you think is the best argument that Plato could have used to justify this conclusion (he himself used several, but here only one is required). You should give this argument in your own way- what counts is the quality of your argument, not how faithful it is to Plato's writings. However your argument should not use any facts or ideas about the world that were unknown in Plato's time.

(ii) Describe what happens if two conducting wires are placed parallel to each other on a frictionless surface (so they are free to move) and then current is passed through them in parallel directions. Draw this set-up, and show the currents and the direction of the forces on the wires when current is flowing.

How is this explained in terms of magnetic fields? You will find it helpful to show the fields on the diagram as well.

Then explain what you think will happen if only one of the wires has a current flowing through it, but it is an *Alternating current*, ie., it is oscillating rapidly, back and forth, in time. Will this affect the other wire, and if so how? How can we think about this in terms of a field?

(iii) In view of your answer to (ii), how do you think Plato would have viewed electromagnetic fields? Are the fields accessible to our senses? If so, then how? If not, then how can we know about them? Are they a kind of Platonic form? A lengthy answer is not required here.

B(3): One of the great discoveries of 20th century physics is that not only are there atoms, but that these are hierarchical in structure. This structure involves essential quantum features.

(i) Describe the Hydrogen atom as it is now understood by quantum physics. You should begin at the scale of the atom itself (ie., a scale of roughly 1 Angstrom), and discuss how we now understand the behaviour of the single electron in this atom. Draw a diagram showing the interaction between the proton and the electron as a function of their distance apart. Now draw a 2nd diagram showing the energies of the bound electron quantum states in this potential- the energies being $\epsilon_n = -R/n^2$, where n is the principal quantum number of the electron states, and $R = 13.6\ eV$.

Suppose the atom was in its ground state. How could one excite it to an excited state with $n = 2$, and what would be the change in energy of the electron?

(ii) Why would the whole picture of the Hydrogen atom that we have break down if quantum mechanics was not valid? Suppose for example that the system was derived by classical mechanics, so that the electron orbits around the nucleus. Explain briefly what would then happen to the electron, and why (remember that we would then be dealing with a moving classical charge).

(iii) The nucleus of a ^{238}U atom contains 92 positively charged protons, and 146 electrically neutral neutrons. Why do the protons not just instantaneously fly apart? Draw the potential acting on a single proton in the U atom, as a function of the distance from the centre of the nucleus.

(iv) As is well known, the ^{238}U nucleus can decay, for example by the emission of an α-particle (2 protons and 2 neutrons bound together). This takes a very long time (billions of years!). How does this happen (you can use a picture to explain this), and why does it take so long?

B(4): It is interesting to speculate on what Plato would have thought about quantum mechanics. Let us first look at some key features of quantum mechanics.

(i) Explain what is meant by the "wave-particle duality". You should discuss this question by referring to the 2-slit interference experiment, and discussing it for something like photons or electrons (or any other system you care to pick). It will be helpful to show what happens in such experiments under different conditions, with the aid of diagrams. Explain carefully what is seen on the screen when (a) one of the slits is open, and then (b) when both are open. Explain why these results are incompatible with either a particle or a wave picture.

(ii) an electron-positron pair in a state of zero angular momentum mutually annihilate, emitting a pair of photons with zero *total* angular momentum (ie., zero total helicity, for photons).

Now the photons separate by a very large distance, and one sets up an apparatus which measures the helicity of one of them (call it 'photon A'). What is the probability of finding that photon A has helicity +1?

Suppose we have also set up an apparatus to look at the other photon (photon B). If instead of measuring photon A, we instead measure the helicity of photon B, what is the probability we will find that it is +1?

Finally, suppose we measure the helicity of photon A, and immediately afterwards that of photon B (so quickly that no signal can possibly travel from A to B). If we find that photon A has helicity +1, what now is the probability that photon B will have helicity +1?

Note that you are not being asked to justify your answers for these 3 situations- all you have to do is give the answers.

(iii) The following definition of an 'element of physical reality' was given by Einstein:

'If, without in any way disturbing a system, we can predict with certainty (i.e. with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to the physical quantity.'

Consider again your answers to the last question- concerning the photon helicities. Under which of the 3 circumstances described above can we consider the helicity of photon B to be an 'element of reality', according to the definition of Einstein? Which property of the system of 2 photons is *always* an element of reality, again according to the definition of Einstein?

(iv) In your opinion, can we relate the idea of an 'element of physical reality', as discussed by Einstein, with the idea of a '*form*', as discussed by Plato? To answer this question you should very briefly explain what Plato meant by 'forms' (without giving any of his arguments for their existence), and then explain how they may or may not be related to Einstein's 'elements'.

END OF EXAM