Phys 340: FINAL EXAMINATION

Thursday, 22nd April, 2004; 12.00 noon-2.30 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).

No electronic equipment or devices of any kind are allowed into the exam (including calculators). You can use pens, pencils, and erasers, but no notes may be brought to the exam.

SECTION A

A(1): Describe what happens when a beam of light, travelling through air, meets a flat interface between air and glass (Hint: if you do not know this, recall what you see when standing outside a shop window on a bright sunny day). A diagram may be helpful here. Quantitative details are not asked for, but the directions of the light beams should be roughly correct.
Why do the results of this pose a problem for a particle theory of light?

A(2): Show in a diagram the magnetic field lines generated by a time-invariant current flowing in a closed loop of wire. Now explain why it is that a short bar magnet shows a similar field pattern. Why is that if we heat the magnet, it loses its magnetism?

A(3): The photoelectric effect was first explained by Einstein in terms of light quanta (ie., 'photons'). Explain briefly what the photoelectric effect is, why it contradicts the wave picture of light, and in what way the photon hypothesis resolves this contradiction.

A(4): Describe briefly the basic cosmological picture advocated by Aristotle. In what ways did Galileo's discovery of the moons of Jupiter upset the Aristotelian picture?

A(5): A typical Vancouver radio station broadcasts at a frequency of 100 MHz (ie., 10^8 oscillations every second). Given that the velocity of light is roughly 3×10^8 ms^{-1}, what is the wavelength of the photons carrying the radio signal? Microwaves for some telecommunications (eg., cell phone) have a typical frequency more like 10-100 GHz (ie., $10^{10} - 10^{11}$ oscillations per second). Suppose you were driving in a tunnel under a bridge- what would you expect to happen to your radio and telephone signals?

A(6): The 3rd law of motion of Descartes reads as follows:

'*a body coming into contact with a stronger one loses none of its motion; but on coming into contact with a weaker one, loses as much as it transfers to the weaker one*'

Consider a situation where a bullet with a mass of 10 g, moving at 1000 ms^{-1}, hits and buries itself in a stationary block of wood of mass 1 kg. What is roughly the motion of the combined object after this?
This result illustrates the contradiction between Newton's laws of dynamics and the 3rd law of Descartes. Describe very briefly what is the contradiction.

A(7): Two of the most striking predictions from Einstein's theory of gravitation are (i) black holes, and (ii) an expanding universe.

For each of these two predictions, explain one astronomical observation or set of observations which gives evidence confirming them.

A(8): Explain briefly how Plato thought of an ideal 'circle' in his theory of Forms. In what way could we come to know the properties of this circle? What relationship did it have to a circle we might draw on a piece of paper?

SECTION B

B(1): A 'naively realistic' idea about the role of experiment, and of the observer, in understanding the world are summarized in Francis Bacon's idea of 'Immaculate Perception', or theory-free observation, in which the observer plays an entirely passive external role:

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

Consider now the following examples of experimental observation:

(i) A metallic antenna has a rapidly time-varying oscillatory current running through it, causing the electrons to oscillate back and forth. Some distance away is another metallic receiver. Describe how, according the the classical theory of electromagnetism, a signal is transmitted between the two. Can we say that the receiver is directly observing the antenna? Or the EM field?

(ii) A large collection of sodium atoms in a streetlight decay from an excited state to its ground state, emitting photons of energy roughly 2 eV. In each of the millions of cells in the retina of the eye there are molecules capable of absorbing a wide range of energies. Describe what you think happens in the retina when the eye is turned towards the streetlight. What will happen if the intensity of the streetlight is turned to very low values?

(iii) A classic 2-slit experiment is being done on electrons. Describe now what happens to the electrons if you illuminate the paths of the electrons with a light beam having a wavelength λ much less than the distance between the slits (still keeping both slits open).

(iv) Comment on Bacon's idea in view of these 3 examples of observation. Which of the three most closely approximates his idea? Can you think of any other kinds of observation that really are very much like what he was thinking of?

B(2): Some of the basic 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 also what happens when the intensity of the photon or electron source is reduced. By appealing to obvious properties of waves and particles, explain why these results, taken together, are incompatible with either a particle or a wave picture.

(ii) A 'buckyball' molecule has a mass of roughly 1.4×10^{-24} kg. Given that Planck's constant is roughly $h = 7 \times 10^{-34}$ Js, and that the wavelength of the buckyball probability wave is given as usual by $\lambda = h/p$, where p is the buckyball momentum, find the wavelength for a buckyball moving at a velocity of 1 mm/sec.

Suppose that we wanted to localise the buckyball inside a volume so that its uncertainty Δx in position was roughly the same as the buckyball size, ie., with Δx roughly 5 Angstroms (ie., 5×10^{-10} m). What then would be the uncertainty in velocity of the buckyball?

(iii) Suppose we send a beam of atoms having a spin through a 'Stern-Gerlach' apparatus, designed to measure which way the spin is pointing. We start by putting all the spins into a state $|\rightarrow\rangle$ (ie., pointing to the right); recall that this is also equal to the superposition $|\rightarrow\rangle = [|\uparrow\rangle + |\downarrow\rangle]$, where $|\uparrow\rangle$ point up and $|\downarrow\rangle$ points down.

What will we see if the apparatus is oriented horizontally, so as to measure whether the spins are left or right?

What will we see if the apparatus is oriented vertically, so as to measure whether the spins are up or down?

Now suppose we instead put half the atoms in the beam into a state $|\uparrow\rangle$, and half into a state $|\downarrow\rangle$. What will we now see if we repeat the same measurements as before (with the apparatus first horizontal and then vertical)?

B(3): Questions about geometry and dynamics.

(i) Describe the retrograde motion of a planet like Jupiter, by showing what is seen in the sky over a period of several years.

Now show how this motion is explained in the old Ptolemaic epicycle theory. Again, a diagram would be useful, showing how the sun, earth, and Jupiter are supposed to move.

Then, show the motion of these 3 bodies according to the Copernican theory. You should also show how it is that the retrograde motion in the sky is explained in this Copernican picture.

(ii) Consider the geometry of figures like circles, triangles, etc., on the 2-dimensional surface of a sphere. A circle of radius r on this sphere, is defined as the set of all points lying at a distance r from a given central point- measured by extending a line of length r across the surface from the central point.

Describe roughly how the circumference C (given in Euclidean geometry by $C = 2\pi r$) will vary as the radius r is increased. Supposing you lived on the surface of the sphere, and were quite incapable of seeing or measuring outside this 2-dimensional world- how could you nevertheless determine the size of the 3-dimensional sphere?

(iii) An 'axiomatic system' uses a set of elementary symbols, which can be put together into 'strings' of symbols (ie., 'propositions'), using some set of rules. Explain how one can make an axiomatic system out of these symbols, ie., what the term 'axiom' refers to, and what it means to derive a true proposition in this axiomatic system.

Euclidean geometry is defined by 5 axioms about points, lines, etc. Can you give a theorem in Euclidean geometry which distinguishes it from any non-Euclidean geometry? Apart from the difference in circumference of a circle between the two geometries, can you explain another 2 tests which one could use to decided whether one was living in a Euclidean or non-Euclidean geometry?

B(4): Atomic Nuclei

Nuclear particles, or 'nucleons' (positively charged protons and neutral neutrons) are extremely dense- when packed together in a nucleus the typical density is about 10^{15} tons/m^3, or 10^{15} g/cm^3 (so a cubic centimeter has a mass of about 10^{15} g, ie., a billion tons). A neutron star is almost entirely composed of matter at this density.

(i) Estimate the mass of a sand grain composed of neutron star matter.

(ii) A sphere of neutron star material of radius 60 m (about 10^5 times smaller than the radius of the earth) would nevertheless have the mass of the entire earth. How much larger would the surface gravity be on the surface of this sphere than it would on the earth's surface (remember Newton's law of gravitational force)

(iii) What binds the nucleons together, ie, what stops the positively charged protons from flying apart from each other? Describe the 2 kinds of force acting between nuclear particles. Then show what sort of potential energy curve results for a proton as a function of its distance from the other nucleons in a nucleus.

(iv) Briefly describe what is (a) nuclear fission, and (b) nuclear fusion. Using your answer to (iii), explain briefly what is the quantum-mechanical reason that fission can occur. Finally, in what way are these processes related to energy production in the stars?

END OF EXAM