JPU200Y – The Way of Physics
Feb. 15, 2001 Test
Answers and Marking Scheme

Short Answer (Marked by Ele Willoughby)

1. **We used *operational definitions* to define the words <u>wave</u> and <u>particle</u>. What is an operational definition? Two sentences maximum please.**

An operational definition is an operation, i.e. some experimental procedure, whose result defines the word or words under consideration.

2. **Multiple choice! Choose the best answer below. The electron is:**
   - **A) A wave.**
   - **B) A particle.**
   - **C) All of the above.**
   - D) **None of the above**.

Either C or D get full marks. (David Harrison prefers D.)

3. **For the double slit experiment for electrons, we are observing an interference pattern at the observing screen. What are the electrons doing at the slits at this time? Two sentences maximum please**.

This question has no answer (beyond the mathematical equations of Quantum Mechanics).

Stating that the chances of an electron going through one of the slits is 50%. (4 points provided no suggestion that we could know which was occurring was made.)

4. **We have said that essentially Einstein made a single new statement in 1905, whose logical consequences are the entire Special Theory of Relativity. What is that statement? One sentence maximum please.**

The speed of light has the same value relative to all observers.

All motion in inertial frames of reference is relative. (3 points)

Einstein was attempting to answer the question of what he would see if he pursued a beam of light at the speed of light. (3 points)

5. **When at rest relative to us a barn is 20 m long and a pole is 25 m long. If the pole is approaching the barn at a high enough speed relative to the barn, its length contracts to less than 20 m and it will (briefly) fit into the barn. But in the frame where the pole is stationary its length is still 25 m, but the barn is moving towards the pole at high speed and is even less than 20 m long; apparently the pole can not fit into the barn. Resolve this seeming paradox. Four sentences maximum please.**

The pole fits relative to both frames. In the pole frame, the signal from when the front of the pole strikes the back of the barn, travelling no faster than speed of light, does not catch up with the front of the barn until after it has passed the back of the pole. Thus the barn "stretches" until the pole fits inside it. (Special Relativity, then, says that there is no such thing as a perfectly rigid body.)

Since the pole fits in the barn frame, it must fit in all frames. (3 points)

Correctly identifying *simultaneity* as the way to resolve the paradox. . (3 points)

6. **Relative to Lou, his twin sister Sue blasts off to Alpha Centauri, travels there at one-half the speed of light, and then returns to Earth at one-half the speed of light. Therefore when Sue and Lou are reunited, Sue is younger than Lou. However, relative to Sue, Lou moves away from her at one-half the speed of light, and then moves back towards her at one-half the speed of light. Therefore, since Lou is moving relative to Sue, Lou should end up the younger twin. But we can not simultaneously have Sue younger than Lou and Lou younger than Sue. Resolve this "Twin Paradox." Two sentences maximum please.**

The problem is that the analysis in Sue's frame is wrong because she is not in an inertial frame of reference. In any inertial frame Sue will end up the younger twin.

Also acceptable: Sue's timeline is longer than Lou's.

7. **What is a *tachyon*? One sentence maximum please. (The correct answer does not involve the TV show *Star Trek*.) If tachyons exist at all, in class we described three properties that they must have. What are they? Three sentences maximum please.**

A tachyon is an object which, if it exists, always travels at a speed greater than the speed of light relative to us. (3 points)

It takes infinite energy to slow a tachyon down to the speed of light (1 point)
If the tachyon has real energy, its rest mass is imaginary (1 point)
If some observer sees a tachyon moving from point A to point B, a second observer, moving at slow speeds relative to the first, can see the same tachyon moving from B to A. (1 point)

Accept •erenkov radiation in place of one of the three properties above provided it is stated that it is a property of a *charged* tachyon.

Accept that the tachyon's *energy* increases as the speed decreases.

Accept the statement "some observers would see the tachyon going backwards in time."

8. **Einstein described his *Equivalence Principle* of 1907 as "the happiest thought of my life." What is the Equivalence Principle? One sentence maximum please.**

Gravitational fields are equivalent to an accelerating reference frame.

Stating a specific example instead of the general principle. (5 points)

9. What is the difference between an *open* and a *closed* universe? Three sentences maximum please.

An open universe is one in which its expansion will continue forever. A closed universe is one in which its expansion will eventually stop and reverse.

Also acceptable: An open universe has an overall geometry of spacetime similar to a saddle, while a closed universe as an overall geometry similar to the surface of a sphere.

Also acceptable: In an open universe there are no parallel light rays: any two light rays will eventually intersect if extended far enough. In a closed universe there are an infinite number of light rays that will never intersect with each other.

10. In 1998 Perlmutter et al. published results of measurements of the speed and distance of supernovae relative to the Earth. Both Science magazine and The New Scientist magazine called this the most important result of science for that year. What do the data indicate about the universe that caused this work to receive such acclaim? Two sentences maximum please.

That the rate of expansion of the universe is increasing.

Just stating that the universe is expanding. (3 points)

Long Answer

1. We have stated that Quantum Mechanics seems to suggest that the word *observer* is not appropriate in describing how we interact with the world, and that *participator* is a better choice. What is the difference in the worldview indicated by these two different words? Why does Quantum Mechanics seem to prefer one over the other? Are there fields of academic inquiry outside of the physical sciences that still use the classical concept of observers? (Marked by David Harrison)

The central idea of the classical worldview is that, at least in principle, one may reduce the disturbance introduced into a system by our observing it to a negligible level. Thus an observer merely sees what is going on in some system without appreciably disturbing it This leads to the idea that there is some physical reality “out there” independent of its observation. (15 points)

Stating that the disturbance is zero: -7 points

A participator is an integral part of the process of a measurement. The observer and the observed can not be separated. (15 points)

Stating only that the measurement has some effect: - 5 points

In Quantum Mechanics and its experimental tests we learn that for some measurements, such as the double slit for electrons, the effect of our “looking” introduces irrevocable qualitative changes in the system being measured. Thus we have participated in the creation of the new physical circumstance that we are measuring. This is the heart of Heisenberg's Uncertainty Principle. (7 points)

Many fields in the social sciences still cling to the idea of *observers*, although the paradigm is not nearly as universal as it was even a decade ago. (3 points)

2. **In 1971 Hafele and Keating flew an atomic beam cesium clock eastward around the world on commercial airliners. They flew another atomic beam cesium clock westward around the world. Assume that these airborne clocks were both travelling at the same speeds relative to the Earth, and at the same altitudes. A third clock remained in their laboratory at the U.S. Naval Observatory in Washington D.C. When the three clocks were brought back together they did not all measure the same elapsed time. According to Special Relativity, which clock or clocks measured the greatest elapsed time, and which clock or clocks measured the least elapsed time? According to General Relativity, which clock or clocks measured the greatest elapsed time and which clock or clocks measured the least elapsed time? Be sure to think carefully about inertial reference frames in answering this question. Be sure to clearly indicate how you arrived at your answers. (Marked by David Harrison)**

The clock that runs the slowest measures the *least* elapsed time. (If the clock has stopped, it is running at the slowest rate possible and measures zero elapsed time.) (5 points)

According to Special Relativity, moving clocks run slow relative to clocks that are stationary. (5 points)

When analysed in a good inertial frame, such as by someone in outer space, due to the Earth's rotation on its axis the westbound clock, the one coming closest to keeping up with the Sun's apparent motion, is the most stationary and therefore runs the fastest. The Earthbound clock is moving faster than this westbound clock, and the eastbound clock is moving the fastest of the three. Thus the eastbound clock is running slowest. (15 points)

Thus, according to Special Relativity the eastbound clock measured the least elapsed time and the westbound clock measured the most elapsed time. (3 points)

According to General Relativity, clocks in gravitational fields run slowly relative to clock in less strong gravitational fields. (5 points)

The Earthbound clock is in the strongest gravitational field and runs the slowest; using the assumptions of this question the other two clocks run at the same faster rate. (4 points)

Therefore, according to General Relativity the earthbound clock measured the least elapsed time and the two around-the-world clocks measured the most elapsed time. (3 points)

(For the actual experiment, the airborne clocks were not always at the same altitudes or moving at the same speeds relative to the Earth.)

3. **We have from time to time described the features that make a physical theory a good one. What are those characteristics? Why do those characteristics have anything to do with whether the theory is good or not? How does the General Theory of Relativity measure up when compared to those characteristics? Isn't**

a good theory by definition simply one that is correct? (Marked by Justin Podur)

Even if it were possible for a physical theory to *be* correct, it would be impossible for us to ever *know* its correctness. We can only compare its predications to experiment. At any time we could disprove the theory by showing a wrong prediction, but can never prove that the theory is correct.

A good theory, then, must:

- Be concise. (2 points) A long list of phenomena won't do. (3 points) General Relativity is certainly concise: it is based on only three principles. (3 points) The fact that the fusion of those principles is a highly complex mathematical structure doesn't count as being non-concise. (In fact, although complex the General Theory is a single equation.) (2 extra points for style, clarity, additional examples, logic.)
- Be elegant. (1 point) Nobody wants to deal with an ugly theory. (2 points) Beauty is in the eye of the beholder, but many people find the worldview given us from General Relativity to be beautiful. (2 points) (2 extra points for style, clarity, additional examples, logic.)
- Be broad. (2 points) The wider the range of physical phenomena covered by the theory the better. (3 points) General Relativity qualifies here too: it describes all of gravitation, cosmology, and the effects of non-inertial reference frames. (3 points) (2 extra points for style, clarity, additional examples, logic.)
- Be predictive (2 points) with testable predictions. (2 points) The theory must make predictions of physical phenomena and relationships that previously were unknown. (3 points) General Relativity makes many such predictions, many of which have been tested. None of the predictions have been experimentally shown to be wrong. (4 points) (2 extra points for style, clarity, additional examples, logic.)