JPU200Y – The Way of Physics
Spring Term Test
February 14, 2002

Answers and Marking Scheme

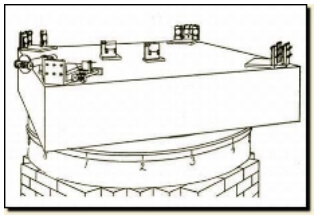
Short Answer (60 points) – Marked by David Harrison

There are 10 short answer questions, each to be marked out of 6 points.

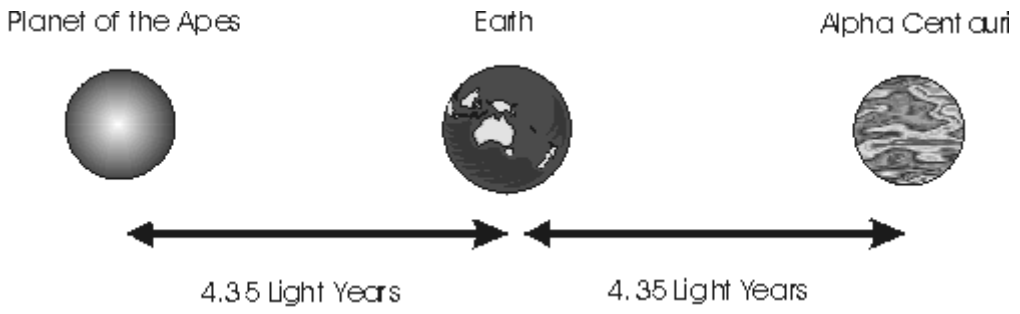
1) Newton thought that light was a particle. Huygens thought that light was a wave. In the early 1800's Young resolved the controversy by means of an experiment. What experiment did Young perform? According to the experimental results, who was correct: Newton or Huygens? Two sentences maximum.

    Young did the double slit experiment for light. It was not necessary to state what the result of the experiment was. (3 pts)
    The experiment showed that Huygens was correct (3 pts)

2) In the Michelson-Morley experiment, the interferometer, as shown, is adjusted so that the light is displaying constructive interference at the light detector. Then the apparatus is rotated by 90 degrees about a vertical axis. What did Michelson and Morley expect the light detector to measure as the interferometer is rotated? What did Michelson and Morley actually observe? Two sentences maximum.

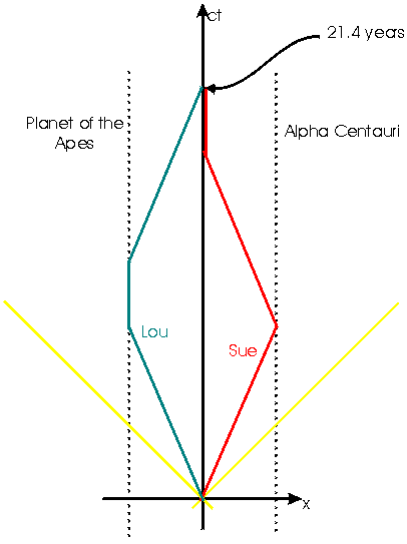


    They expected to see the detector to measure the light cycling from constructive to destructive to constructive etc. interference. (4 pts)
    What they observed was no shifts in the light. (2 pts)
    Stating only that they expected to see a change: 3 pts maximum.
    Stating that they expected c to be different: 2 pts. maximum



3) Sue and Lou are identical twins, born at the same instant. Assume that the Earth is a good inertial reference frame. Alpha Centauri is 4.35 light-years away from Earth. The Planet of the Apes is 4.35 light-years away from Earth in the opposite direction. Assume that both Alpha Centauri and the Planet of the Apes are stationary relative to the Earth. At the moment called the "present" by us on Earth, Sue blasts off for Alpha Centauri. She travels at 0.5 c with respect to the Earth. When she arrives at Alpha Centauri she immediately turns around and returns to Earth at 0.5 c with respect to the Earth. When she arrives back at Earth she lands. At the moment called the present by us on Earth, Lou blasts off for the Planet of the Apes, travelling at 0.5 c with respect to the Earth. When he arrives at the Planet of the Apes he is captured and put into jail on the surface of the planet. After Lou has been in jail for four years he escapes, steals his rocket ship, and returns to Earth travelling at 0.5 c with respect to the Earth. When he arrives back at Earth he lands. Draw a spacetime diagram for us remaining on Earth. Be sure to label the axes. Include the light cone. Draw the worldlines for Sue and for Lou. When they are re-united on Earth which twin is younger and why?

The figure shows the diagram drawn to scale. The marking was fairly lenient about getting the scale correct.
Correct axes and labels: 1 pt.
Correct light cone: 1 pt.
Correct topology (shape) of Sue and Lou's worldlines: 1 pt.
Speeds of Sue and Lou clearly less than c: 1 pt.
They end up the same age: 1 pt.
Because the worldlines are the same length: 1pt.
Some students correctly explained the fact that they are the same age using a symmetry argument: also 1 pt.



4) Define the rest mass of an object. One sentence maximum.

The mass of an object relative to an observer for whom it is at rest. (6 pts).
At rest relative to an inertial reference frame: 3 pts maximum.
No "relative to" or "with respect to": 2 pts maximum.

5) At age 16 Einstein asked what would he see if he pursued a beam of light at the speed of light. According to his Special Theory of Relativity what is the answer to his original question? One sentence maximum.

He can not pursue the beam of light at the speed of light. (6 pts).
"See light moving at c": 2 pts only.

6) The density of an object is defined as its mass divided by its volume. Imagine an object is shaped like a sphere as measured by someone at rest with respect to it. This observer measures the density of the object. With respect to a second observer the object is moving at a high speed. Is the density of the object with respect to this second observer smaller, larger or the same value as that measured by the first observer? Why? Three sentences maximum.

The density is larger. (2 pts)
The mass increases. (2 pts)
The volume decreases (2 pts).

7) The General Theory of Relativity considers observers in any state of relative motion, including relative accelerations. The theory turns out to also be a theory of gravitation. How can the consideration of relative acceleration also be a consideration of gravity? Two sentences maximum.

The Equivalence Principle. (6 pts)
Gravitation is equivalent to acceleration. (also 6 pts).
Relating to Mach's Principle: 2 pt deduction.

8) The General Theory of Relativity has made a number of predictions. Some of these have been experimentally tested and found to be correct, and others have not been tested. Others have been tested but the results are only suggestive or ambiguous. None have been tested and found to be wrong. For each of the following predictions of General Relativity, indicate whether or not it has been tested, and if it has been tested what are the results of the test. For each case, the answer is either "**Not tested**" or "**Tested confirmed**" or "**Tested ambiguous**."

A) Stellar aberration
   Tested confirmed (1pt)
B) Gravitational time dilation
   Tested confirmed (1 pt)
C) Gravitational length contraction
   Not tested (1pt)
D) Black holes
   Tested Ambiguous (1pt)
   Also accepted: “Tested Confirmed”
E) Expanding universe
   Tested confirmed (1 pt)
F) Gravity waves
   Tested ambiguous (1 pt)

9) For a black hole, the region that is the a distance equal to the "Schwarzschild radius" away from the centre is called the "event horizon." Why is it given that name? Two sentences maximum.

   No event that occurs inside it can be known to us outside it. (6 pts).

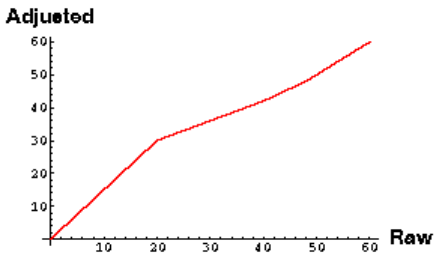
10) What aspect of his General Theory of Relativity caused Einstein to introduce a Cosmological Constant in 1915? What recent experimental results have caused some cosmologists to introduce another cosmological constant? Two sentences maximum.

   GR predicted an expanding universe. (3 pts).
   Recent data have shown that the rate of expansion of the universe is increasing (3 pts).
   Stating Perlmutter’s name without giving the result: 1 pt only.

Re-scaling

The results of the Short Answer section were re-scaled to U of T marks. The U of T mark is in slot #4 of the test booklet, and is written in black. The raw mark is to the left of the re-scaled one, and is written in red. Here I discuss how the re-scaling was done. The mapping was:

Raw Points	Adjusted Points
0	0
20	30
30	36
40	42
48	48
60	60



Re-scaled marks were then rounded up to the nearest integer. The statistics for the Short Answer section are:

	Raw	Re-scaled
Mean/60	.62 (i.e. 62%)	.68
Standard Deviation/60	.23	.18
Quartiles/60	.47, .67, .79	.58, .70, .80
Percent A's (> 47 pts)	25%	26%
Percent B's (42 – 47 pts)	21%	28%
Percent C's (36 – 41 pts)	15%	18%
Percent D's (30 – 35 pts)	9%	14%
< 30 pts	31%	14%

You can see the overall mark distribution on the test from ***STORM*** as soon as your mark has been entered by your tutor.

Long Answer (40 points)

What follows is not so much a marking scheme as key points and guidelines used to mark the question.

1) A person who objects to the theories of relativity says: "Relativity is concerned only with how we observe things, not what is really happening. Hence it is not a scientific theory, since science deals with reality." Discuss. (Marked by Ele Willoughby)
   A) The nature of reality; [Any decent discussion of these ideas was worth 10 marks, and a supporting example worth ~5. Note some of these points are not independent. No additional marks were granted for re-wording a concept.]
      - There is no Newtonian objective reality with an absolute frame of reference
      - There is no privileged frame of reference
      - Science has only ever dealt with observables and observations of reality, not reality itself which is inaccessible
      - "what is really happening" really does depend on motion and mass nearby
      - "what is really happening" cannot be established
      - relativity does deal with reality/realities and the dynamics of spacetime
      - the objector is making the mistake of extrapolating from slow to fast, and has been prejudiced by Newtonian physics

- several aspects have been tested and some confirmed (especially that c is a constant and all the "weird effects" in special relativity fall out of that).

B) Discussions of the role of science and the scientific method [Good discussions of this were granted up to 10 points];
- scientists observe trends, make predictions based on data and theory
- theories are testable and will change if they fail a test (clinging to Newton is anti-science or superstition)
- as a theory it is concise, elegant, broad, predictive
- in fact it is more successful than many theories because it tells us theories because it tells us both what happens and how we observe!

Students lost marks if they claimed it was proven (as opposed to parts of it being confirmed by experiment), or worse that the attitude was correct, with no acknowledgement that any of it had been tested (only one student fell in that trap). Several students called relativity non-classical and claimed that it involved participators rather than observers. Some think "Newtonian" and "classical" are interchangeable.

2) In everyday units, the speed of light is 1,079,253,000 km/hr. Why is it such a large number? Remember that in the "better" units we have been using exclusively in our discussions of relativity, the speed of light is exactly one, which is not a large number. Include this fact in your discussion. (Marked by Ele Willoughby)
- light speed is fast (faster than various examples) (5)
- secular vs. religious units; should use meters (10)
- parable of surveyors used to justify idea that not measuring time in m is like measuring E-W in km and N-S in miles (5)
- c is a conversion factor for measuring time in meters (5) and if c=1, E=m (5), and using this scaling makes light speed a 45 degree line on a spacetime diagram (2)
- we did not plan for this when units were developed
- km/h seemed reasonable prior to 1905 for everyday velocities (10)
- no prior concept of a maximum velocity or a invariant velocity from which units could be derived (5)
- time was not previously linked to space, so it was not self-evident that time should be measured in m (5)
- size of c is arbitrary since it depends on units employed (1 is not a large number)

This adds to more than 40, but no one had all of the above. Ignoring that c = 1 if time is measured in meters: deduct 5 marks

3) An electron is observed to leave the electron gun, and a fraction of a second later is observed at some particular position at the screen.

Between the gun and the screen is a barrier with two small slits. Heisenberg wrote that "the path [of the electron from the gun to the screen] comes into existence only when we observe it." Discuss the meaning of Heisenberg's statement. (Marked by Samir Iskander)

A) Mention the Double slit experiment causes electrons to interfere and the interference pattern appears on the screen. (wave nature of the electron) ~ 5 MARKS
B) Path of the electron through the slits is indeterminable, probabilistic and cannot be known for certain unless we perform a measurement. ~10 marks
C) Attempts to measure causes the wave to nature to disappear, we get particle nature. ~ 7 MARKS
D) Use of a specific example to show how the measurement is attempted, i.e. the variation of the light's intensity of the bulb or the wavelength or covering one of the slits. ~ 5 marks
E) The observer vs. the participator (through the attempts at measuring) ~ 10 MARKS
F) Uncertainty Principle and its role on limiting our knowledge. ~ 3 MARKS
    - Students lost marks if they claimed that Heisenberg did the actual double slit experiment and 'deduced' from the observations his principle.