SPH 4U MATTER-ENERGY INTERFACE REVIEW

Write numbers 1 to 11 in your notebook. Indicate beside each number whether the corresponding statement is true (T) or false (F). If it is false, write a corrected version.

1. The speed of light in water is $\frac{c}{n}$, where $n = 1.33$ is the index of refraction of water. The speed of light in water is thus less than the speed of light in a vacuum. This fact violates the speed-of-light postulate of the special theory of relativity.
2. We customarily say that Earth revolves around the Sun. We can also say that the Sun revolves around Earth.
3. If events E_1 and E_2 are simultaneous in an inertial frame, then no observers stationary in the same frame will regard E_1 as occurring before E_2.
4. (a) Any two observers moving with a clock will agree on the rate at which it ticks.
   (b) Any two observers moving relative to each other, and simultaneously moving relative to a clock, will agree on the rate at which the clock ticks.
   (c) The observer moving with a clock, and measuring the time between ticks, measures the proper time between ticks.
5. Earth rotates on its axis once each day. To a person observing Earth from an inertial frame of reference in space, that is, stationary relative to Earth, a clock runs slower at the North Pole than at the equator. (Ignore the orbital motion of Earth about the Sun.)
6. A young astronaut has just returned to Earth from a long mission. She rushes up to an old man and in the ensuing conversation refers to him as her son. She cannot possibly be addressing her son.
7. (a) An object will be greater in length if the observer is moving with the object than if the object is moving relative to the observer.
   (b) An observer at rest relative to the moving object measures the object's proper length.
8. Relativistic effects such as time dilation and length contraction are for practical purposes undetectable in automobiles.
9. The total relativistic energy of an object is always equal to or greater than its rest mass energy.
10. Since rest mass is a form of energy, a spring has more mass when the coils are compressed than when relaxed.
11. The classical laws of conservation of energy and conservation of mass do not need to be modified for relativity.

Write numbers 12 to 23 in your notebook. Beside each number, write the letter corresponding to the best choice.

12. You are in a windowless spacecraft. You need to determine whether your spaceship is moving at constant nonzero velocity, or is at rest, in an inertial frame of Earth.
    (a) You can succeed by making very precise time measurements.
    (b) You can succeed by making very precise mass measurements.
    (c) You can succeed by making very precise length and time measurements.
    (d) You cannot succeed no matter what you do.
    (e) You are in a position not correctly described by any of these propositions.
13. You and your friend recede from each other in spacecraft in deep space without acceleration. In an inertial frame on your spaceship, your friend is receding at a speed of $0.9999c$. If you direct a light beam at your friend, and your friend directs a light beam at you, then
    (a) neither beam will reach the ship to which it is directed
    (b) you will see your friend's light arrive at a speed of $2c$, and your friend will see your light arrive at a speed of $2c$
    (c) you will see your friend's light arrive at a speed of c, and your friend will see your light arrive at a speed of c
    (d) one of you will see light arrive at a speed of c, and the other will see light arrive at $2c$
    (e) none of these propositions is true
14. Simultaneity is
    (a) dilated
    (b) absolute
    (c) invariant
    (d) relative
    (e) none of these
15. The Michelson–Morley experiment established that
    (a) there is no observable ether wind at the surface of Earth
    (b) the ether moves at c as Earth travels in its orbit
    (c) the ether is an elastic solid that streams over Earth
    (d) Earth does not move with respect to the Sun
    (e) none of these

16. A Klingon spaceship is approaching Earth at approximately $0.8c$ measured relative to Earth. The spaceship directs a laser beam forward directly through your physics classroom window. You measure the speed of this light to be
   (a) $1.8c$
   (b) $1.0c$
   (c) $0.9c$
   (d) $0.8c$
   (e) $0.2c$

17. You are an astronaut heading out toward a star. In the inertial frame of the star, you are steering directly for the star and are moving at constant speed. You can determine that you are in motion by
   (a) the slowing down of on-board clocks
   (b) the contraction of on-board metre sticks
   (c) your increase in mass
   (d) the increase in your heart rate
   (e) none of these

18. A clock, designed to tick each second, is moving past you at a uniform speed. You find the moving clock to be
   (a) ticking slowly
   (b) ticking quickly
   (c) accurate
   (d) running backward
   (e) none of these

19. The proper time between events E_1 and E_2 is
   (a) the time measured on clocks at rest with respect to E_1 and E_2
   (b) the time measured on clocks at rest in an inertial system moving properly with respect to E_1 and E_2
   (c) the time measured on clocks moving uniformly with respect to E_1 and E_2
   (d) the time between E_1 and E_2 as measured by a clock in a national-standards laboratory, such as the National Research Council in Ottawa
   (e) none of these

20. There are about 2.81×10^9 heartbeats in an average lifetime of 72 years. Space travellers who are born and die on a spaceship moving at a constant speed of $0.600c$ can expect their hearts to beat a total of
   (a) $(0.600)(2.81 \times 10^9)$ times
   (b) 2.81×10^9 times
   (c) $(0.800)(2.81 \times 10^9)$ times
   (d) $(1.25)(2.81 \times 10^9)$ times
   (e) none of these

21. A mass–spring system oscillates up and down with a period T when stationary in an inertial frame anchored in an Earthbound observer. The same system is then moved past the Earthbound observer, with a velocity which in the observer's frame is constant and of magnitude $0.50c$. The observer now determines the period to be
   (a) $0.50T$
   (b) $0.87T$
   (c) $1.0T$
   (d) $1.2T$
   (e) $2.0T$

22. According to the effect of length contraction, from the viewpoint of an observer stationary with respect to a body moving at a uniform speed relative to the observer,
   (a) the body is not now contracted but would contract if it were to accelerate
   (b) the body contracts along the direction of motion
   (c) the time it takes for a clock incorporated in the body to tick contracts
   (d) the body contracts in some direction transverse to the direction of its motion
   (e) none of these

23. The energy output of the Sun is 3.7×10^{26} J/s. Matter is converted to energy in the Sun at the rate
   (a) 4.1×10^9 kg/s
   (b) 6.3×10^9 kg/s
   (c) 7.4×10^1 kg/s
   (d) 3.7×10^9 kg/s
   (e) none of these

11. F
12. D
13. C
14. D
15. A
16. B
17. E
18. A
19. A
20. B
21. D
22. B
23. A

1. F
2. T
3. T
4. (a) T (b) F (c) T
5. F
6. F
7. (a) T (b) T
8. T
9. T
10. F

Jerstanding Concepts

1. Suppose you are standing at a railroad crossing, watching a train go by. Both you and a passenger in the train are looking at a clock on the train.
   (a) Which of you measures the proper time interval?
   (b) Which of you measures the proper length of the train car?
   (c) Which of you measures the proper length between the railroad ties under the track?

   Justify your answers.
2. A baseball player hitter pops a fly straight up; it is caught by the catcher at home plate. Identify which of the following observers is able to record the proper time interval between the two events:
   (a) a spectator sitting in the stands
   (b) a fan sitting on the couch and watching the game on TV
   (c) the shortstop running in to cover the play

   Explain your answer in each case.
3. When you are flying in a commercial jet, it appears to you that the airplane is stationary and Earth is moving beneath you. Is this point of view admissible? Discuss briefly.
4. Does time dilation mean that time actually passes more slowly in moving reference frames or that it only seems to pass more slowly? Discuss your answer.
5. Two identically constructed clocks are synchronized. One is put into orbit around Earth, and the other remains on Earth. When the moving clock returns to Earth, will the two clocks still be synchronized? Explain your answer.
6. Why is it that a pair of synchronized clocks, rather than a single clock, is needed for measuring any time interval other than a proper time?
7. Describe two instances in which the predictions of the special theory of relativity have been verified.
8. A spaceship passes you at a speed of 0.92c. You measure its length to be 48.2 m. How long would the ship be when at rest?
9. The straight-line distance between Toronto and Vancouver is 3.2×10^3 km (neglecting the curvature of Earth). A UFO is flying between these two cities at a speed of 0.70c relative to Earth. What do the voyagers aboard the UFO measure for this distance?
10. A UFO streaks across a football field at 0.90c relative to the goal posts. Standing on the field, you measure the length of the UFO to be 228 m. The UFO later lands, allowing you to measure it with a metre stick. What length do you now obtain?
11. Two spaceships, X and Y, are exploring a planet. Relative to this planet, spaceship X has a speed of 0.70c, while spaceship Y has a speed of 0.86c. What is the ratio of the values for the planet's diameter that each spaceship measures, in a direction that is parallel to its motion?
13. Nuclei of radium, an unstable element, disintegrate by emitting a helium nucleus with a kinetic energy, in the inertial frame of the laboratory, of about 4.9 MeV. Calculate the rest-mass equivalent of this energy.
14. A nuclear power reactor generates 3.00×10^9 W of power. In one year, what is the change in the mass of the nuclear fuel due to the energy conversion? (*Hint:* Recall that a 1-W power source delivers 1 J/s).
15. The electron and the positron each have a rest mass of 9.11×10^{-31} kg. In a certain experiment, an electron and a positron collide and vanish, leaving only electromagnetic radiation after the interaction. Each particle is moving at a speed of 0.20c relative to the laboratory before the collision. Determine the energy of the electromagnetic radiation.
16. The total energy of a certain muon, a particle with a rest energy of 105.7 MeV, is 106.7 MeV. What is its kinetic energy?
17. (a) Suppose the speed of light is only 47.0 m/s. Calculate the relativistic kinetic energy in an inertial frame of the road, which would be possessed by a car of rest mass 1.20×10^3 kg and moving at 28.0 m/s in that frame.
    (b) Calculate the ratio of this relativistic kinetic energy to the kinetic energy as computed in Newtonian mechanics.
18. The Big Bang, which is a theory predicting the origin of the universe, is estimated to have released 1.0×10^{68} J of energy. How many stars could half this energy create, assuming the average star's mass is 4.00×10^{30} kg?
19. A supernova explosion (**Figure 1**) of a star with a rest mass of 1.97×10^{31} kg, produces 1.02×10^{44} J of kinetic energy and radiation.
    (a) How many kilograms of mass are converted to energy in the explosion?
    (b) Calculate the ratio of the mass destroyed to the original mass of the star.

8. 123 m
9. 2.28×10^3 km
10. 523 m
11. 1.4
12. 1.58×10^{-30} kg·m/s
3. 8.7×10^{-30} kg
4. 1.05 kg
5. 0.615 MeV
6. 1.0 MeV
7. (a) 6.49×10^5 J
   (b) 1.4:1
8. 1.39×10^{20} stars
9. (a) 1.13×10^{27} kg
   (b) 5.75×10^{-5}:1

Write numbers 1 to 11 in your notebook. Indicate beside each number whether the corresponding statement is true (T) or false (F). If it is false, write a corrected version.

1. Planck proposed that energy is radiated in bundles he called quanta. The energy of a single quantum is directly proportional to its wavelength.
2. At the cutoff potential, even the most energetic photoelectrons are prevented from reaching the anode.
3. For a given photoelectric surface, the longer the wavelength of light incident on it, the higher the cutoff potential.
4. In the Compton effect, high energy photons strike a surface, ejecting electrons with kinetic energy and lower-energy photons.
5. Photons have momentum whose value is given by $p = \frac{hc}{\lambda}$.
6. When light passes through a medium, its behaviour is best explained using its particle properties, whereas when light interacts with matter, its behaviour is best explained using its wave properties.
7. The diffraction of electrons revealed that particles have wave characteristics.

11. In the atom we think of the electron as a particle moving in a circular orbit whose wave properties predict its exact position and velocity.

Write numbers 12 to 24 in your notebook. Beside each number, write the letter corresponding to the best choice.

12. In the photoelectric effect, increasing the frequency of the light incident on a metal surface
    (a) decreases the threshold frequency for the emission of photoelectrons
    (b) decreases the number of photoelectrons emitted
    (c) increases the threshold frequency for the emission of photoelectrons
    (d) increases the kinetic energy of the most energetic photoelectrons
    (e) does not affect the kinetic energy of the photoelectrons

Use Figure 1 to answer questions 13 to 15. Figure 1 shows the results of an experiment involving the photoelectric effect. The graph shows the currents observed in the photocell circuit as a function of the potential difference between the plates of the photocell when light beams A, B, C, and D, each with its own wavelength, were each directed at the photocell.

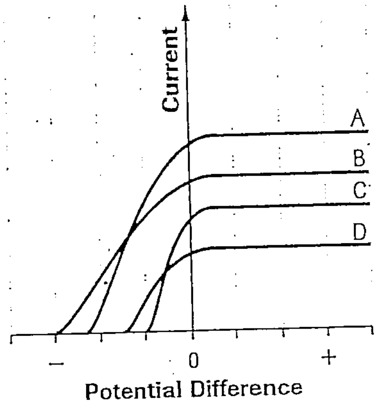

Figure 1
Graph of current versus potential difference for four different beams of light (for questions 13, 14, 15)

13. Which of the beams of light had the highest frequency?
    (a) A (b) B (c) C (d) D (e) They all had the same frequency.
14. Which of the beams of light had the longest wavelength?
    (a) A (b) B (c) C (d) D (e) They all had the same wavelength.
15. Which of the beams of light ejected photoelectrons having the greatest momentum?
    (a) A (b) B (c) C (d) D (e) They all ejected photoelectrons having the same momentum.

Use Figure 2 to answer questions 16 and 17. Here, electrons of a single energy are focused into a thin pencil-like beam incident at 90° on a very thin crystalline film of gold. On the other side of the film, a pattern of circular rings is observed on a fluorescent screen.

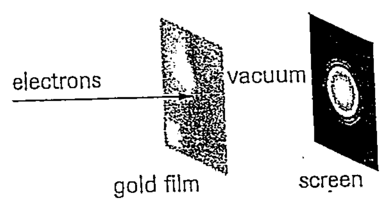

Figure 2
For questions 16 and 17

16. This experiment provides evidence for
    (a) the wave nature of matter
    (b) the high speed of electrons
    (c) circular electron orbits around nuclei
    (d) the spherical shape of the gold atom
    (e) none of these
17. If the energy of the electrons were increased, the rings would
    (a) assume the shape of an increasingly eccentric ellipse
    (b) remain essentially unchanged
    (c) become less intense
    (d) increase in width
    (e) decrease in size

1. F
2. T
3. F
4. T
5. F
6. F
7. T
~~8. F~~
~~9. F~~
~~10. F~~
11. F
12. D
13. B
14. C
15. B
16. A
17. E

Understanding Concepts

1. Explain, using the photon theory, why we cannot see in the dark.
2. In a photographer's darkroom light is very damaging to the sensitive film emulsions, ruining photographs. However, we may use red light bulbs when working with some types of film. Using the photon theory, explain why red light does not affect the photographic film.
3. When monochromatic light illuminates a photoelectric surface, photoelectrons with many different speeds, up to some maximum value, are ejected. Explain why there is a variation in the speeds.
4. Calculate the longest wavelength of light that can eject electrons from a surface with a work function of 2.46 eV.
5. Light with the wavelength 6.0×10^2 nm strikes a metal having a work function of 2.3×10^{-19} J. Calculate the maximum kinetic energy, in joules, of the emitted electrons and the potential difference required to stop them.
6. Light with wavelength 4.30×10^2 nm falls onto a photoelectric surface. The maximum kinetic energy of the photoelectrons is 1.21 eV. Calculate the work function of the surface.
7. Calculate the momentum of a 410-nm photon of violet light.
8. Calculate the energy, in electron volts, required to give an electron an associated de Broglie wavelength of 7.5×10^{-10} m.
9. An electron is accelerated from rest through a potential difference of 1.50×10^4 V. Calculate its associated de Broglie wavelength.
10. An electron is fired at a metal target, reaching a speed of 1.00×10^6 m/s. On impact, it rapidly decelerates to half that speed, emitting a photon in the process. Calculate the wavelength of the photon.
11. (a) Calculate the wavelength of a photon that has the same magnitude of momentum as an electron moving with a speed of 2.52×10^6 m/s.
    (b) Calculate the de Broglie wavelength associated with the electron.
12. How does the diffraction of electrons by a thin nickel foil illustrate the concept of wave–particle duality?
18. State the principle of complementarity.
19. Explain the differences and similarities between the interference of water waves and the interference of electrons.
20. Compare how particles are viewed in quantum mechanics versus how they are viewed in classical mechanics.

Write the numbers 26 to 40 in your notebook. Beside each number place the expression or expressions, equation or equations, required to complete the text.

26. Any frame of reference in which the law of inertia holds is called a(n) ___?___ frame. Any frame in which the law of inertia does not hold is called a(n) ___?___ frame.
27. Michelson and Morley's interferometer experiment showed that ___?___.
28. According to the effects of length contraction, a body contracts along the direction of its ___?___.
29. The only mass that can be measured directly is ___?___.
30. Planck proposed that energy is radiated in discrete bundles called ___?___.
31. The threshold frequency for photoelectron emission from a photoelectric material is ___?___ (the same, different) for different metals.
32. The higher the frequency of the light, the ___?___ (higher, lower) the cutoff potential.
33. Matter waves predict the ___?___ that a particle will follow a particular path.
34. A 4.0-eV photon is absorbed by a metal surface with threshold energy 3.0 eV. An electron can be emitted with a kinetic energy in the range of ___?___ eV to ___?___ eV.

34. 0 to 1.0 eV
33. probability
32. lower
31. different
30. quanta
29. rest mass
28. length
27. ether does not exist
26. inertial, noninertial

11. (a) 2.88×10^{-10} m
    (b) 2.88×10^{-10} m
10. 582 nm
9. 1.00×10^{-11} m
8. 2.68 eV
7. 1.62×10^{-27} kg·m/s
6. 1.67 eV
5. 1.0×10^{-19} J, −0.64 eV
4. 5.04×10^{-7} m

29. The graph in **Figure 1** shows the kinetic energy of the most energetic photoelectrons as a function of the frequency of light falling on the cathode in a photoelectric cell.

(a) According to the graph, what potential difference would be required to stop all the emitted electrons if the incident light had a frequency of 7.5×10^{14} Hz?

(b) What is the physical significance of the intercept of the graph with the frequency axis (x-axis)?

(c) What is the physical significance of the intercept obtained when the graph is extrapolated back to the kinetic energy axis (y-axis)?

(d) Use the graph to determine a value for Planck's constant.

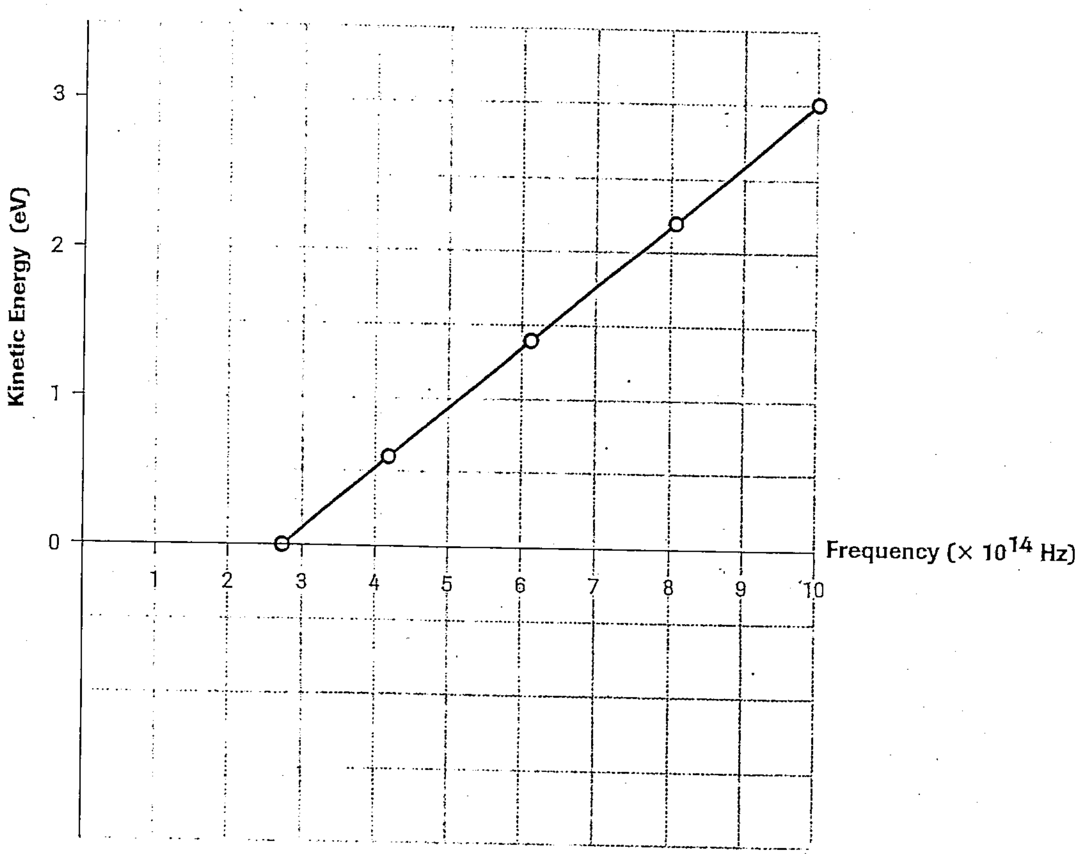

Figure 1
Maximum kinetic energy versus frequency (for question 29)