

The Thirty-second Annual SLAPT Physics Contest  
Washington University in Saint Louis  
April 22<sup>nd</sup>, 2017

Comprehensive Exam

$$g = 9.8 \text{ m s}^{-2}$$

$$G = 6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$$

$$e = 1.6 \times 10^{-19} \text{ C}$$

$$c = 3 \times 10^8 \text{ m} \cdot \text{s}^{-1}$$

$$R = 8.314 \text{ J mol}^{-1} \cdot \text{K}^{-1}$$

$$k_B = 1.38 \times 10^{-23} \text{ m}^2 \cdot \text{kg} \cdot \text{s}^{-2} \cdot \text{K}^{-1}$$

$$\epsilon_0 = 8.85 \times 10^{-12} \text{ m}^{-3} \cdot \text{kg}^{-1} \cdot \text{s}^4 \cdot \text{A}^2$$

$$\mu_0 = 1.26 \times 10^{-6} \text{ m} \cdot \text{kg} \cdot \text{s}^{-2} \cdot \text{A}^{-2}$$

$$h = 4.135 \times 10^{-15} \text{ eV} \cdot \text{s}$$

Please answer the following questions on the supplied answer sheet. You may write on this test booklet and keep it for your records. Only the answer sheets will be scored.

Your sheets must have your name, your school, and COMPREHENSIVE on them.

1. A rocket is launched from the origin with an acceleration of  $20.0 \text{ m/s}^2$  at an angle of  $60^\circ$  above the horizontal. The launch acceleration lasts for 2.0 seconds at which time the fuel is exhausted. The rocket then falls with an acceleration of  $9.8 \text{ m/s}^2$  downward. What is the maximum height?

- a) 20.4 m
- b) 40.4 m
- c) 61.2 m
- d) 95.7 m
- e) 121.6 m

2. An airplane is flying in horizontal flight at a constant velocity. The weight of the airplane is 85,000 N. The wings produce a lift force that is perpendicular to the wings, and a drag force that is parallel to the wing. The engine produces a forward thrust force of 4,000 N. Which of the following statements is true?

- a) The lift force on the airplane is 89,000 N upward.
- b) The drag force on the airplane is 81,000 N downward.

- c) The drag force on the airplane is 4,000 N backward.
- d) The lift force on the airplane is zero.
- e) The drag force on the airplane is zero.

3. Two swimmers, A and B, start at the same time and place on the bank of a river with flow  $\mathbf{v}$ . Both move at speed  $\mathbf{c}$  ( $\mathbf{c} > \mathbf{v}$ ) relative to the water. Swimmer A swims downstream a distance  $\mathbf{L}$  and then upstream a distance  $\mathbf{L}$ , returning to the starting point. Swimmer B swims so that their motion is perpendicular to the banks of the river at all times and swims a distance  $\mathbf{L}$  before turning around and returning. What is the order that the swimmers return to the starting point?

- a) Swimmer A returns first, then swimmer B returns.
- b) Swimmer B returns first, then swimmer A returns.
- c) They return at the same time.
- d) Not enough information to know.

4. The velocity at the midway point of a ball able to reach a height  $\mathbf{y}$  when thrown with velocity  $\mathbf{v}_0$  straight up from the origin is:

- a)  $\frac{v_0}{2}$
- b)  $\sqrt{v_0^2 - 2gy}$
- c)  $\sqrt{\frac{v_0^2}{2}}$
- d)  $\sqrt{v_0^2 + 2gy}$
- e)  $gy$

5. An astronaut orbits the earth in a space capsule whose height above the earth is equal to the earth's radius. How does the weight of the astronaut in the capsule compare to her weight on the earth?

- a) Her weight is equal to her weight on earth.
- b) Her weight is equal to one-fourth her weight on earth.
- c) Her weight is equal to one-half of her weight on earth.
- d) Her weight is equal to one-third of her weight on earth.
- e) Her weight is equal to zero.

6. An astronaut in a space suit is motionless in outer space. The propulsion unit strapped to her back ejects some gas with a velocity of 30 m/s. The astronaut recoils with a velocity of 0.5 m/s. If the mass of the astronaut and space suit after the gas is ejected is 120 kg and the mass of the gas ejected is 2 kg, then the total kinetic energy after the ejection of the gas is:

- a) 0 J
- b) 915 J
- c) 3,430 J
- d) 4,150 J
- e) 56.7 kJ

7. The sum of two vectors is zero. What can you conclude about the two vectors?

- a) They point in the same direction.
- b) They are perpendicular.
- c) They point in opposite directions.
- d) One has twice the magnitude of the other.

8. If the frequency of a harmonic oscillator doubles, while its amplitude remains the same, how much does the maximum value of acceleration change?

- a) 2
- b) 4
- c)  $\sqrt{2}$
- d)  $2/\pi$
- e) It does not change.

9. If the frequency of a violin string is to be increased by 50%, what change in tension must be applied?

- a) 5%
- b) 22%
- c) 50%
- d) 70.7%
- e) 125%

10. Transverse waves propagate at 39.7 m/s in a string that is subjected to a tension of 70.5 N. If the string is 16.1 m long, what is its mass?

- a) 0.219 kg
- b) 0.371 kg
- c) 0.720 kg
- d) 0.606 kg

11. If a source of sound is moving towards you, how does that motion affect the wavelength of the sound waves that you observe?

- a) It increases it.
- b) It decreases it.
- c) It does not affect it.

12. If a piece of metal has a hole in it and the metal is heated, how does the area of the hole change?

- a) It increases.
- b) It remains the same.
- c) It decreases.

13. Two identical containers are each filled with 10 moles of gas. The two containers are at the same temperature, yet the internal energies of the two gasses differ. How can this be?

- a) The molecules of the two gasses have different masses.
- b) The molecules of the two gasses have different numbers of degrees of freedom.
- c) This could be explained by either (a) or (b).
- d) Neither (a) nor (b) could explain this.

14. Which of the following is not true? The electric force:

- a) decreases with the inverse of the square of the distance between two charged particles
- b) between an electron and a proton is much stronger than the gravitational force between them
- c) between two protons separated by a distance **d** is larger in magnitude than that between two electrons separated by the same distance **d**
- d) may be either attractive or repulsive

15. A solid spherical conductor is given a net nonzero charge. The electrostatic potential of the conductor is:

- a) largest at the center
- b) largest on the surface
- c) largest somewhere between the center and the surface
- d) constant throughout the volume

16. Two capacitors with differing capacitances are connected first in series and then in parallel. Which combination has the larger net capacitance?

- a) The pair in series.
- b) The pair in parallel.
- c) The two combinations have the same net capacitance.
- d) There is not enough information to decide between these choices.

17. Consider two identical resistors wired in series (one behind the other). If there is an electric current through the combination, the current in the second resistor is:

- a) greater than the current through the first resistor
- b) equal to the current through the first resistor
- c) half the current through the first resistor
- d) less than the current through the first resistor, but not necessarily half as much

18. A 100-watt light bulb carries a current of 0.5 A. The total charge passing through it in one hour is:

- a) 120 C
- b) 600 C
- c) 1800 C
- d) 3600 C

19. An electron moves in the  $\mathbf{z}$  direction, through a uniform magnetic field in  $\mathbf{y}$  direction. The magnetic force on the electron is:

- a) in the negative  $x$  direction
- b) in the positive  $x$  direction
- c) in the negative  $y$  direction
- d) in the negative  $z$  direction

20. As used in the laws of reflection and refraction, the “normal” direction is:

- a) any convenient direction
- b) tangent to the interface
- c) along the incident ray
- d) perpendicular to the electric field vector of the light
- e) perpendicular to the interface

21. Monochromatic light of wavelength  $\lambda$  passes through a small slit of width  $d$  onto a screen a distance  $D$  away ( $D \gg \lambda > d$ ). If the slit width,  $d$ , is decreased what is the effect on the width of the first maximum of the diffraction pattern?

- a) It increases.
- b) It decreases.
- c) Two slits are needed to form a diffraction pattern.
- d) It does not change.

22. When you stand in front of a plane mirror, your image is:

- a) real, erect, and smaller than you
- b) real, erect, and the same size as you
- c) virtual, erect, and smaller than you
- d) virtual, erect, and the same size as you
- e) real, inverted, and the same size as you

23. If the mass of a particle is zero, its speed must be:

- a) infinite
- b) 0
- c)  $c$
- d) any speed less than  $c$
- e) any speed greater than  $c$

24. A man sits in the back of a canoe in still water. He then moves to the front of the canoe and sits there. Afterwards the canoe:

- a) in its original position and not moving.
- b) in its original position and moving forward.
- c) is forward of its original position and moving forward.
- d) is rearward of its original position and moving forward.
- e) is rearward of its original position and not moving.

25. A 2.0-N avocado is traveling at 2.0m/s. It strikes a 4.0-N nectarine, which is stationary. The two fruits stick together. Their common final speed is:

- a) 0.5 m/s
- b) 0.67 m/s
- c) 1.0 m/s
- d) 1.33 m/s
- e) 2.0 m/s

26. A spaceship that is at 20 light-years from Earth (as seen from Earth) travels towards it at a speed of  $0.8c$ . According to a passenger on the ship, how long does their trip to Earth take?

- a) 25 years
- b) 16 years
- c) 12 years
- d) 15 years
- e) 20 years

27. When 12eV photons strike a cobalt plate, a 7V potential difference is required to stop the photoelectric current from flowing. What is the smallest photon frequency that will generate a current on this metal?

- a)  $1.69 \times 10^{15}\text{Hz}$ .
- b)  $2.90 \times 10^{15}\text{Hz}$ .
- c)  $1.21 \times 10^{15}\text{Hz}$ .
- d)  $1.78 \times 10^{15}\text{Hz}$ .
- e) There is no lowest frequency.

The next two questions refer to a telescope with an objective lens of focal length 20cm and an eyepiece of focal length 4cm.

28. What will the total length of the telescope tube be for the system to function properly?

- a) 16cm
- b) 20cm
- c) 14cm
- d) 25cm
- e) 24cm

29. What is the telescope's angular magnification and what type of images does it produce?

- a) 4, inverted
- b) 5, upright
- c) 4, upright
- d) 5, inverted
- e) 6, inverted

30. The leaves of a positively charged electroscope diverge more when an object is brought close to it.

That object must be:

- a) An insulator.
- b) A conductor.
- c) Negatively charged.
- d) Positively charged.
- e) Uncharged.

31. You are walking along the equator, where the Earth's magnetic field has no component perpendicular to its surface, but is pointing in the North-South direction. If you hold a metal rod in your hands as you walk from east to west, in which direction must you orient the rod to maximize the motional EMF across it?

- a) North-South.
- b) East-West.
- c) Up-Down.
- d) The motional EMF is independent of the rod's orientation.

32. Singly ionized  $\text{He}^+$  ions with charge  $+e$  move in a straight line with speed  $v$  through a velocity selector (a region with mutually perpendicular  $\mathbf{E}$  and  $\mathbf{B}$  fields, both perpendicular to the direction of the moving ions). Now replace the singly ionized  $\text{He}^+$  ions with doubly ionized  $\text{He}^{++}$ . What speed must these  $\text{He}^{++}$  ions have in order to travel in a straight line through the same velocity selector?

- a)  $4v$
- b)  $2v$
- c)  $v/2$
- d)  $v/4$
- e)  $v$

33. A cube of side length  $a$  has a single positive charge  $Q$  inside. If all the dimensions of the cube are increased by a factor of 3, the total electric flux through the box:

- a) will increase by a factor of 9
- b) will increase by a factor of 3
- c) will remain unchanged
- d) will decrease by a factor of 3
- e) will decrease by a factor of 9

34. A sinusoidal plane electromagnetic wave is traveling in vacuum in the  $+\mathbf{x}$  direction. At some instant the electric field, which points in the  $+\mathbf{z}$  direction, is at its maximum positive value  $E_0$  at  $\mathbf{x} = 0, L, 2L, 3L, \text{etc.}$  At that same instant, what is the magnitude of the magnetic field at  $\mathbf{x} = L/4$ ?

- a) 0
- b)  $E/2c$
- c)  $E/c$
- d)  $2E/c$
- e)  $E/4c$

35. A 1kg block of gold (density  $19.3\text{g/cm}^3$ ) is placed on the left arm of a very precise scale, and a 1kg block of aluminum (density  $2.7\text{g/cm}^3$ ) is placed on the right arm. Which way does the scale move?

- a) It does not move
- b) The gold arm moves down
- c) The aluminum arm moves down.

36. Air is pumped into a bicycle tire at constant temperature. The pressure increases because
- a) more molecules strike the tire wall per second
  - b) the molecules are larger
  - c) each molecule is moving faster
  - d) the molecules are farther apart
  - e) each molecule has more internal energy
37. A container of helium gas is at  $73^{\circ}\text{C}$ . To what temperature must the gas be heated if one is to double the average kinetic energy of the helium atoms
- a)  $146^{\circ}\text{C}$
  - b)  $565^{\circ}\text{C}$
  - c)  $692^{\circ}\text{C}$
  - d)  $419^{\circ}\text{C}$
  - e)  $292^{\circ}\text{C}$
38. A listener finds that a siren sitting still emits sound at  $1000\text{Hz}$ . When the same siren is riding on a model plane describing circles centered on the listener, its sound is observed to have
- a) a lower frequency than before
  - b) a higher frequency than before
  - c) the same frequency as before
  - d) a lower or higher frequency depending on whether the motion is clockwise or counterclockwise
39. Sound from a tuning fork travels through air and enters water. The speed of sound is greater in water than in air. The frequency of the sound wave in water is \_\_\_\_\_ its frequency in air, while its wavelength in water is \_\_\_\_\_ its wavelength in air.
- a) the same as; greater than
  - b) the same as; less than
  - c) greater than; the same as
  - d) greater than; greater than
  - e) smaller than; smaller than

40. Two waves of same amplitude traveling in opposite directions along a string momentarily interfere destructively. What happens to the energy of the string?

- a) It is completely potential energy.
- b) It is completely kinetic energy.
- c) It is momentarily zero.

41. Which of the following describes a transverse wave traveling on a string in the positive  $x$  direction?

- a)  $x(x,t) = A\cos(k(x-vt))$
- b)  $y(x,t) = A\cos(k(x+vt))$
- c)  $z(x,t) = A\cos(k(x+vt))$
- d)  $y(x,t) = A\cos(k(x-vt))$
- e)  $x(x,t) = A\cos(k(x+vt))$

42. A 1.0-kg block and a 2.0-kg block are pressed together on a horizontal frictionless surface with a compressed very light spring between them. They are not attached to the spring. After they are released and have both moved free of the spring:

- a) the lighter block will have more kinetic energy than the heavier block.
- b) the heavier block will have more kinetic energy than the lighter block.
- c) both blocks will both have the same amount of kinetic energy.
- d) both blocks will have equal speeds.
- e) the magnitude of the momentum of the heavier block will be greater than the magnitude of the momentum of the lighter block.

43. You are standing on a skateboard, initially at rest. A friend throws a very heavy ball towards you. You can either catch the object or deflect the object back towards your friend (such that it moves away from you with the same speed as it was originally thrown). What should you do in order to MINIMIZE your speed on the skateboard?

- a) Catch the ball.
- b) Deflect the ball.
- c) Your final speed on the skateboard will be the same regardless whether you catch the ball or deflect the ball.

44. In a collision between two objects having unequal masses, how does magnitude of the impulse imparted to the lighter object by the heavier one compare with the magnitude of the impulse imparted to the heavier object by the lighter one?

- a) The lighter object receives a larger impulse.
- b) The heavier object receives a larger impulse.
- c) Both objects receive the same impulse.
- d) The answer depends on the ratio of the masses.
- e) The answer depends on the ratio of the speeds.

45. Consider the following statements about the work done by a conservative force:

- I. It can always be expressed as the difference between the initial and final values of a potential energy function.
- II. It is independent of the path of the body and depends only on the starting and ending points.
- III. When the starting and ending points are the same, the total work is zero.

Which of the above statements are true?

- a) I
- b) I, II
- c) I, III
- d) I, II, III
- e) II, III

46. A ball drops some distance and gains 30 J of kinetic energy. Do NOT ignore air resistance. How much gravitational potential energy did the ball lose?

- a) more than 30 J
- b) exactly 30 J
- c) less than 30 J

47. If the polar ice caps of the Earth were to melt completely and the melted ice redistributed itself uniformly around the globe, what would happen to the length of the day?

- a) It would remain the same.
- b) It would increase slightly.
- c) It would decrease slightly.

48. A rock is thrown vertically upward with initial speed  $v_0$ . Assume a friction force proportional to  $-v$ , where  $v$  is the velocity of the rock, and neglect the buoyant force exerted by air. Which of the following is correct?

- a) The acceleration of the rock is always equal to  $g$ .
- b) The acceleration of the rock is equal to  $g$  only at the top of the flight.
- c) The acceleration of the rock is always less than  $g$ .
- d) The speed of the rock upon return to its starting point is  $v_0$ .
- e) The rock can attain a terminal speed greater than  $v_0$  before it returns to the starting point.

49. A 5-kilogram stone is dropped on a nail and drives the nail 0.025 meter into a piece of wood. If the stone is moving at 10 meters per second when it hits the nail, the average force exerted on the nail by the stone while the nail is going into the wood is most nearly

- a) 10N
- b) 100N
- c) 1000N
- d) 10000N
- e) 100000N

50. The period of a hypothetical Earth satellite orbiting at sea level would be 80 minutes. In terms of the Earth's radius  $R$ , the radius of a synchronous satellite orbit (period 24 hours) is most nearly:

- a)  $3R$
- b)  $7R$
- c)  $18R$
- d)  $320R$
- e)  $5800R$