2021 Academic Challenge

PHYSICS TEST - STATE

<u>This Test Consists of 35 Questions</u>

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GENERAL DIRECTIONS

Please read the following instructions carefully. This is a timed test; any instructions from the test supervisor should be followed promptly.

The test supervisor will give instructions for filling in any necessary information on the answer sheet. Most Academic Challenge sites will ask you to indicate your answer to each question by marking an oval that corresponds to the correct answer for that question. Only one oval should be marked to answer each question. Multiple ovals will automatically be graded as an incorrect answer.

Be sure ovals are marked as ●, not ⊙, ⦶, ◑, etc.

If you wish to change an answer, erase your first mark completely before marking your new choice.

You are advised to use your time effectively and to work as rapidly as you can without losing accuracy. Do not waste your time on questions that seem too difficult for you. Go on to the other questions, and then come back to the difficult ones later if time remains.

***** TIME: 40 MINUTES *****

DO NOT OPEN TEST BOOKLET UNTIL YOU ARE TOLD TO DO SO!

Fundamental Constants

Quantity	Symbol	Value
Avogadro's number	N_A	6.022×10^{23}/mol
Boltzmann's constant	k	1.381×10^{-23} J/K
Electron charge magnitude	e	1.602×10^{-19} C
Permeability of free space	μ_0	$4\pi \times 10^{-7}$ T·m/A
Permittivity of free space	ϵ_0	8.854×10^{-12} $C^2/(N \cdot m^2)$
Electrostatic Constant	$k = (4\pi\epsilon_0)^{-1}$	8.988×10^{9} $N \cdot m^2/C^2$
Planck's constant	h	6.626×10^{-34} J·s
Electron mass	m_e	9.1094×10^{-31} kg
Neutron mass	m_n	1.6749×10^{-27} kg
Proton mass	m_p	1.6726×10^{-27} kg
Speed of light in vacuum	c	2.9979×10^{8} m/s
Universal gravitational constant	G	6.673×10^{-11} $N \cdot m^2/kg^2$
Universal gas constant	R	8.3145 J/(mol·K)

Other information:

Acceleration due to gravity at Earth's surface: $g = 9.80$ m/s^2

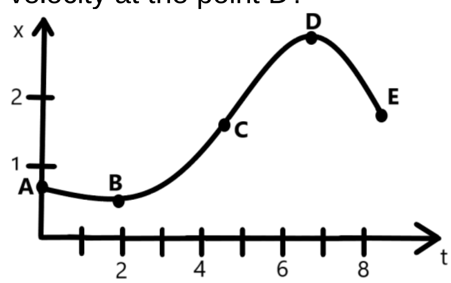
0.00 ^oC = 273.15 K

Academic Challenge
Physics Test (State) – 2021

1. A unit of energy is composed of $\frac{[mass][length]^2}{[time]^2}$. So it would be reasonable to work with a quantity that is $1.83\,\frac{milligrams\cdot(centimeters)^2}{(microsecond)^2}$ though those units might be unwieldy. What would that quantity be in N·m?

a. $1.83 \times 10^{-4} N \cdot m$ b. $1.83\ N \cdot m$ c. $2.37\ N \cdot m$ d. $183\ N \cdot m$ e. $1.83 \times 10^{5} N \cdot m$

2. For an object moving along the x-axis with the position-time graph shown, what best describes the acceleration and velocity at the point D?



a. the velocity is zero and the acceleration is negative
b. the velocity is zero and the acceleration is zero
c. the velocity is zero and the acceleration is positive
d. the velocity is positive and the acceleration is zero
e. the velocity is negative and the acceleration is zero

3. In the situation described in problem 2, what best describes the velocity and acceleration at the point C on the graph?

a. the velocity is zero and the acceleration is negative
b. the velocity is zero and the acceleration is zero
c. the velocity is zero and the acceleration is positive
d. the velocity is positive and the acceleration is zero
e. the velocity is negative and the acceleration is zero

4. What is the magnitude of the displacement vector from the origin to the point x = 6.00 m, y = 9.00 m, and z = -4.00 m?

a. 10.0 m b. 10.8 m c. 11.0 m d. 11.5 m e. 19.0 m

5. Though there is some debate, one account is that Nolan Ryan is the person who pitched the fastest baseball pitch ever. His pitch was measured with a speed of 48.3 m/s. If his arm pushed the 0.145 kg baseball for a distance of 1.89 m when he pitched it, what was the average force he applied to the ball?

   a. 89.5 N b. 179 N c. 1230 N d. 1790 N e. 4260 N

6. Two cars are driving past a policeman who is sitting by the side of the road measuring their speed by radar. He measures the first car with a constant speed of 35.8 m/s and the second car comes by in the same direction but 2.00 seconds later with a constant speed of 38.0 m/s. Both cars maintain their constant speed. How far down the road does the second car overtake the first car?

   a. 78.4 m b. 583 m c. 618 m d. 1170 m e. 1240 m

7. In the situation described in problem 6, what constant acceleration would the policeman need (starting from rest) to catch the second car in 2000 m, assuming he started just as the second car passed him?

   a. 0.361 m/s^2 b. 0.693 m/s^2 c. 1.28 m/s^2 d. 1.44 m/s^2 e. 2.77 m/s^2

8. Consider a smooth flat table with a small hole in the center. A light string is threaded through the hole. A mass of 5.27 kg is attached to the string on top of the table and a mass of 3.63 kg is attached below the table. What speed will the top mass have to move with so that it makes circles of diameter 0.666 m on the table and the bottom mass hangs without moving?

   a. 1.00 m/s b. 1.50 m/s c. 1.81 m/s d. 2.12 m/s e. 3.08 m/s

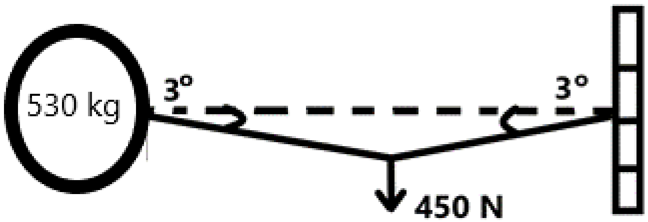
9. A 155 kg object is dropped (starts from rest) from 3630 km above the Earth's surface. ($R_E = 6.37x10^6$ m and $M_E = 5.97x10^{24}$ kg) What is its initial acceleration?

   a. 0.00 m/s^2 b. 3.98 m/s^2 c. 9.80 m/s^2 d. 30.2 m/s^2 e. $3.02x10^7$ m/s^2

10. A 3.15 kg block is sliding down a long incline. When first measured its speed is 3.00 m/s. The speed is measured again after one second and found to be 4.40 m/s. Two seconds after the initial measurement the speed is 5.80 m/s. Three seconds after the initial measurement the speed is 7.20 m/s. What is the magnitude of the net force applied to this block?

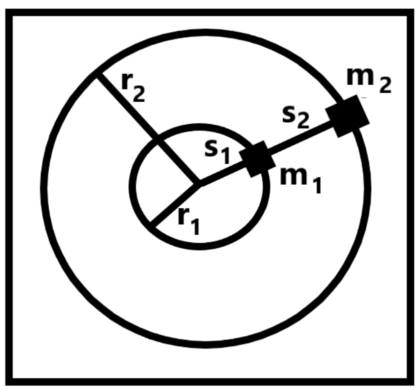
    a. 0.00 N b. 4.41 N c. 13.9 N d. 16.1 N e. 26.5 N

11. A round 530 kg block sits on a rough surface. The coefficient of kinetic friction between the block and the surface is 0.387. A metal cable is tightly strung between the block and a nearby wall (immovable wall). A person is moving the block but it is very heavy. So they go to the center of the cable and pull perpendicular to its length as shown in the figure (view from above). What is the net force on the block when the cable makes an angle of 3.00° as shown?



a. $2010\ N$ b. $1560\ N$ c. $2290\ N$ d. $4300\ N$ e. $8600\ N$

12. Two masses (m_1 = 0.125 kg and m_2 = 0.205 kg) are attached together and to a central rotating post as shown:



They are attached to the post by a length of string s_1 and to each other by a length of s_2. The masses rotate on circular paths on a smooth table with r_1 = 13.2 cm and r_2 = 21.8 cm. They rotate at a constant angular velocity of 8.17 rad/s. What is the tension in string s_1?

a. 1.01 N b. 1.88 N c. 2.98 N d. 3.85 N e. 4.08 N

13. A uniform cylinder of mass 3.45 kg and radius of 7.25 cm is rotating about an axis along its length and through its center with angular velocity of 2.15 rev/s. What is the magnitude of the torque that is required to stop the rotations in 3.92 seconds? (note that for an axis along the center axis: $I_{cylinder} = \frac{1}{2}mR^2$)

a. $4.97 \times 10^{-3} \frac{kg\, m^2}{s^2}$ b. $3.12 \times 10^{-2} \frac{kg\, m^2}{s^2}$ c. $6.25 \times 10^{-2} \frac{kg\, m^2}{s^2}$ d. $8.38 \times 10^{-2} \frac{kg\, m^2}{s^2}$ e. $2.45 \frac{kg\, m^2}{s^2}$

14. How many electrons are in 20.0 ounces (which is 567 g) of pure gold. The atomic mass of gold is 196.97 AMU and the atomic number of gold is 79.

a. $1.37 \times 10^{23}\ electrons$ b. $1.73 \times 10^{24}\ electrons$ c. $4.76 \times 10^{25}\ electrons$
d. $1.37 \times 10^{26}\ electrons$ e. $8.51 \times 10^{26}\ electrons$

15. Which statement is true about simple harmonic motion?

a. The frequency and the period are independent of the amplitude.
b. The acceleration is proportional to the velocity.
c. The velocity is proportional to the displacement.
d. The acceleration is in the same direction as the displacement.
e. The period is independent of the frequency.

16. The famous Cavendish experiment was originally designed to measure

a. The speed of light
b. The charge on the electron
c. The gravitational attraction between known masses
d. The mass and lifetime of the proton
e. The total atmospheric pressure at sea level

17. The Takoma Narrows bridge disaster occurred due to

a. Resonance
b. Earthquake
c. Massive weight from traffic
d. Explosives testing
e. Electrical eddy currents

18. Debye shielding is a plasma physics term related to a plasma's ability to shield out electric potentials. The measure of the distance it takes for the plasma to shield the potential is known as the Debye Length and is defined as:

$$\lambda_D = \left\{\frac{\epsilon_o k T_e}{n e^2}\right\}^{1/2}$$

Where $\epsilon_o = 8.854 \times 10^{-12} \frac{F}{m}$, k is the Boltzmann constant = 1.38×10^{-23} J/°K , e is the charge on the electron = 1.602×10^{-19} C , T_e is known as the electron temperature (related to the motion of the electrons in the plasma, and n is known as the plasma density and is given in particles per cubic meter. If you are given that the Debye length for a certain plasma is 1.35 mm and the electron temperature is 25400 °K what is the plasma density for this plasma?

a. $1.06 \times 10^{-5} \frac{particles}{m^3}$
b. $6.65 \times 10^{7} \frac{particles}{m^3}$
c. $8.98 \times 10^{10} \frac{particles}{m^3}$
d. $6.65 \times 10^{11} \frac{particles}{m^3}$
e. $6.65 \times 10^{13} \frac{particles}{m^3}$

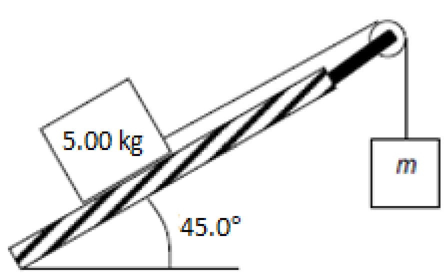
19. How many *n*, *l*, and m_l combinations are there in the *n*=2 atomic shell?

a. 1 b. 2 c. 4 d. 6 e. 8

20. A Carnot heat engine operates between a hot reservoir of 427°C and a cold reservoir of 177°C to accomplish 1850 J of work. How many joules of energy are deposited in the cold reservoir?

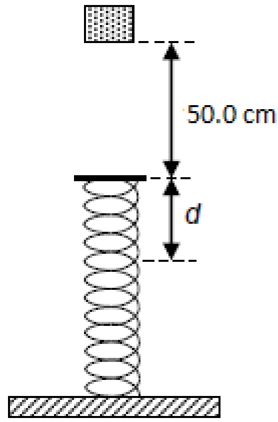
a. 661 J b. 1310 J c. 3160 J d. 3330 J e. 5180 J

21. A 5.00-kg block on a frictionless surface tilted 45.0° to horizontal is attached by a rope to a second block with mass *m* that is freely suspended from the end of the rope, as shown in the diagram. The pulley is frictionless and the masses of the pulley and rope are negligible. If the acceleration of the 5.00-kg mass is 3.00 m/s^2 up the plane, what is the mass *m*?



a. 3.00 kg b. 4.50 kg c. 5.66 kg d. 7.30 kg e. 8.79 kg

22. A 4.00-kg block is released from rest from a distance 50.0 cm above the top, free end of a vertically oriented spring of spring constant 2500 N/m. The bottom end of the spring is fixed to an immovable, horizontal surface. What will be the maximum distance, *d*, the spring is compressed by the block, assuming the spring's natural length is greater than *d*?



a. 11.6 cm b. 14.2 cm c. 15.6 cm d. 20.0 cm e. 25.0 cm

23. In the situation described in problem 22, what is the maximum speed of the block during its motion?

a. 1.26 m/s b. 1.88 m/s c. 2.00 m/s d. 2.35 m/s e. 3.15 m/s

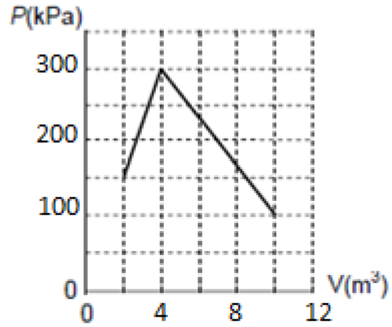
24. A pipe is partially filled with water and a column of air is above the water level. A tuning fork vibrating at 688 Hz is placed near (but not touching) the open end of the pipe. Suppose that water is drained so that the water level decreases at a constant rate of 5.00 cm/s. What is the time between two successive, loud sounds from the pipe? Assume the sound speed in air is 344 m/s.

a. 2.00 s b. 4.24 s c. 5.00 s d. 5.67 s e. 7. 80 s

25. Which of the following lengths is equal to 10^{-12} m?

a. nanometer
b. picometer
c. pentameter
d. attometer
e. femtometer

26. An ideal gas with an initial absolute pressure 150 kPa and volume 2.00 m^3 is taken by the process indicated on the graph to the final pressure 100 kPa and volume 10.0 m^3. How much work was done by the gas on the environment during the process?



a. 1650 kJ   b. 1600 kJ   c. 1870 kJ   d. 2000 kJ   e. 2400 kJ

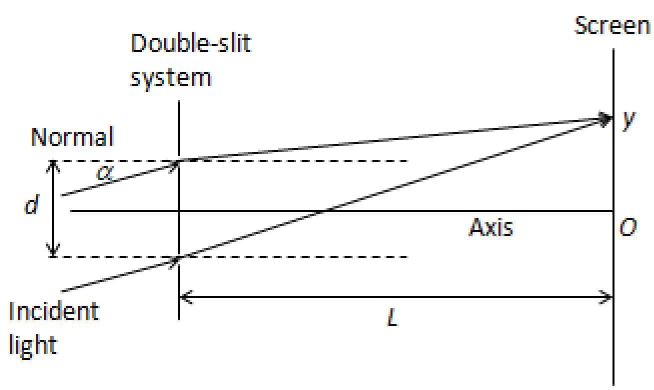
27. Which statement below is correct regarding the Photoelectric Effect?

a. The Photoelectric Effect shows the wave nature of light.
b. The Photoelectric Effect shows the wave nature of the electron.
c. The Photoelectric Effect shows the particle nature of light.
d. The Photoelectric Effect shows the particle nature of the neutron.
e. The Photoelectric Effect shows the particle nature of the proton.

28. On planet X, a 3.00 kg object with a charge of 5.00 mC is levitated and held in equilibrium by an applied electric field. If the magnitude of the electric field required to create the levitation is 5000 V/m, what is the gravitational acceleration at this location?

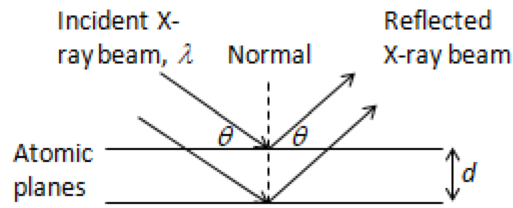
a. 3.68 m/s^2 b. 6.00 m/s^2 c. 8.33 m/s^2 d. 8.97 m/s^2 e. 9.80 m/s^2

29. When light of wavelength λ = 600 nm has a normal incidence on a double-slit system, a bright fringe of order m = 1 is formed 4.80 cm above the axis on a screen a distance L from the system. If the same light is incident with an angle α = 0.700° relative to the normal, as shown in the diagram, what is the position y of the bright fringe of the same order? Assume the slit separation is d = 0.0250 mm and L >> d.



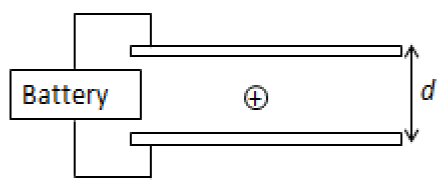
a. 7.24 cm   b. 6.86 cm   c. 5.00 cm   d. 4.80 cm   e. 4.00 cm

30. One way to determine the spacing *d* between atomic planes in a crystal is by X-ray diffraction. Suppose an X-ray beam of wavelength λ is incident on an atomic plane with angle θ, as shown in the diagram, and a strong reflected beam of the first order is observed. What is spacing *d*? Assume λ = 0.130 nm and θ = 10.0°.



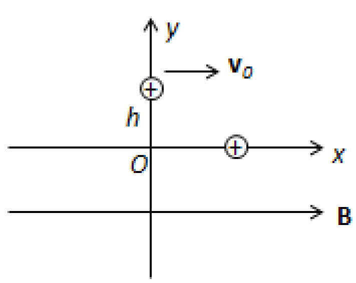
a. 0.749 nm b. 0.524 nm c. 0.374 nm d. 0.257 nm e. 0.195 nm

31. A positively-charged particle is at rest in the space between two infinitely-large, parallel metal plates, separated by distance *d*, as shown in the diagram. One plate is connected to the positive terminal of a battery, and the other is connected to the negative terminal of the same battery. When *d* increases, what would happen to the motion of the particle? Assume the battery's voltage output stays constant.



a. The particle would stay at rest.
b. The particle would move upward at a constant velocity.
c. The particle would move downward at a constant velocity.
d. The particle would accelerate upward.
e. The particle would accelerate downward.

32. A positively-charged particle of mass *m* and charge *q* is projected horizontally with initial velocity $\mathbf{v}_0$ from a height *h* above the horizontal *x* axis, as shown in the diagram. Upon landing on the *x* axis, it immediately enters a uniform magnetic field **B** that is present in the *xy* plane below the *x* axis and directed in the +*x* direction. What is the magnitude of the magnetic force acting on the particle when it enters the magnetic field? Ignore air resistance.



a. qBh b. $qB\sqrt{2gh}$ c. $qB\sqrt{2g}$ d. qv_0B e. $qB\sqrt{v_0^2 + 2gh}$

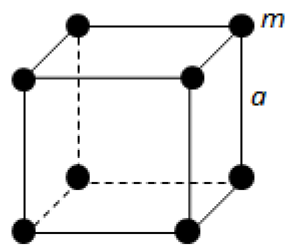
33. A meter stick moves at speed *v* in a direction along its length relative to an observer. In the reference of the observer, the length of the meter stick is measured to be *L*/2. What is *v*? Let *c* be the speed of light in a vacuum.

a. 0.866 *c* b. 0.750 *c* c. 0.600 *c* d. 0.550 *c* e. 0.426 *c*

34. A relativistic particle has a total energy that is three times as much as its rest energy. What is the speed of this particle?

a. 0.200 *c* b. 0.450 *c* c. 0.768 *c* d. 0.850 *c* e. 0.943 *c*

35. A crystal consists of identical cubic unit cells (such as the one shown in the diagram) arranged periodically throughout the three-dimensional space. One atom is associated with each corner of the cell. Each atom has mass *m* and the side length of each cell is a. What is the mass density of this crystal?



a. m/a^3 b. $4m/a^3$ c. $8m/a^3$ d. $m/2a^3$ e. $m/8a^3$