PHYSICSBOWL 2024

March 20 – April 5, 2024

40 QUESTIONS – 45 MINUTES

The 2024 PhysicsBowl, organized by the **American Association of Physics Teachers**, is an opportunity to recognize outstanding high school physics students and their teachers through their performance on this year's contest.

- Schools compete in one of <u>two</u> divisions, each with <u>nineteen</u> regions.
  - *Division 1* is for students *taking physics for the first time* (even if that first course is AP Physics).
  - *Division 2* is for students taking a second (or more) course in physics OR anyone wanting a challenge.
- A school's team score in each division is the sum of the ***<u>five</u>*** highest student scores in that division.
- A school may compete in either or both divisions.

INSTRUCTIONS

Answer sheet: Write and bubble-in the following **<u>REQUIRED</u>** information on your answer sheet:

- Your *<u>Name</u>*
- Your *<u>Teacher's AAPT Teacher code</u>* (given to you by your teacher – only ***one*** code per school!)
- Your *<u>Region</u>* (given to you by your teacher)
- Your *<u>Division</u>* (1 for first-year physics students, 2 for students in a 2^{nd} physics course OR wanting a challenge)

If this information is not properly bubbled, ***you will be disqualified,*** as your official score will be a zero.

Your *<u>School's CEEB code</u>* (given to you by your teacher), though not required, is helpful in the event of a disqualification for identifying your school.

Your answer sheet will be machine graded. Be sure to use a *#2 pencil*, fill the bubbles completely, and make no stray marks on the answer sheet.

Questions: The test is composed of 50 questions; however, students answer only 40 questions.

> **Division 1 students will answer only questions 1 – 40.** Do not answer questions 41 – 50.
>
> **Division 2 students will answer only questions 11 – 50.** Do not answer questions 1 – 10.

Calculator: A hand-held calculator may be used. Any memory must be cleared of data and programs. Calculators may not be shared.

Formulas and constants: Only the formulas and constants provided with the contest may be used.

Time limit: *<u>45 minutes.</u>*

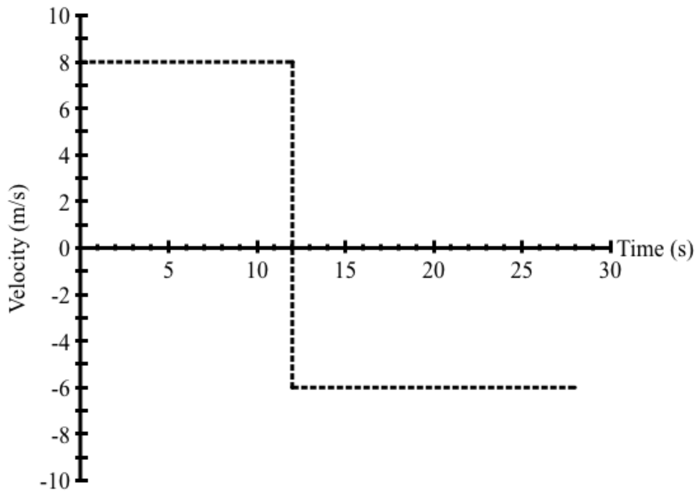
Score: Your score is equal to the number of correct answers (no deduction for incorrect answers). If there are tie scores, the entries will be compared from the end of the test forward until the tie is resolved. Thus, the answers to the last few questions may be important in determining the winner and you should consider them carefully.

Good Luck!

DIVISION 1 STUDENTS START HERE.	DIVISION 2 STUDENTS Go to question #11 on page 4.

Treat $g = 10.0\ \frac{m}{s^2}$ for ALL questions.

Questions 1 - 2 refer to the following graph depicting the velocity of an object from *t* = 0 until *t* = 28 seconds.



1. The average speed of the object for the twenty-eight second interval is …
   a. between 6.0 and 6.5 m/s.
   b. between 6.5 and 7.0 m/s.
   c. 7.0 m/s.
   d. between 7.0 and 7.5 m/s.
   e. between 7.5 and 8.0 m/s.

2. The average velocity of the object for the twenty-eight second interval is …
   a. -2.0 m/s.
   b. -1.0 m/s.
   c. 0.0 m/s.
   d. 1.0 m/s.
   e. 2.0 m/s.

3. A door is hinged on one side, and a force of 15 N is applied perpendicular to the door at a distance of 0.8 m from the hinge. How much torque is applied by this force to the door?
   a. 12 N·m b. 15 N·m c. 18 N·m d. 20 N·m e. 24 N·m

4. A rock is dropped from a cliff in a canyon. Neglecting air resistance, as it falls, which of the following statements about its energy is true, according to the law of conservation of energy?
    a. The total mechanical energy of the rock increases.
    b. The total mechanical energy of the rock remains constant.
    c. The kinetic energy of the rock decreases, but the potential energy remains constant.
    d. The potential energy of the rock decreases, but the kinetic energy remains constant.
    e. The kinetic energy of the rock increases, but the potential energy remains constant.

5. Two people on ice skates are initially at rest while facing one another. One person has a mass of 60 kg and the other 40 kg. They push off each other and move in opposite directions. If the 60-kg skater moves with a speed of 2.0 m/s, what is the speed of the 40-kg skater, assuming no external forces are acting?
    a. $1.0\,\frac{m}{s}$ b. $2.0\,\frac{m}{s}$ c. $3.0\,\frac{m}{s}$ d. $4.0\,\frac{m}{s}$ e. $5.0\,\frac{m}{s}$

6. What is the conversion factor between km/hr^2 and m/s^2?
    a. 7.72 x 10^{-6}
    b. 7.72 x 10^{-5}
    c. 0.278
    d. 2.78 x 10^{-2}
    e. 2.78 x 10^{-4}

7. The radius of the Earth is 3963 miles. What is the surface area of the Earth in square meters?
    a. 4.9 x 10^{7} m^2
    b. 2.6 x 10^{7} m^2
    c. 1.3 x 10^{14} m^2
    d. 2.6 x 10^{14} m^2
    e. 5.1 x 10^{14} m^2

8. A hockey puck is given an initial speed of 10.0 m/s. It slides 50.0 m on the ice before it stops. What is the coefficient of kinetic friction between the puck and the ice?
    a. 0.090 b. 0.10 c. 0.11 d. 0.12 e. 0.13

9. A wooden crate is placed on a flat surface, and three forces act on it: F_1 is applied horizontally to the right, F_2 is applied horizontally to the left, and F_3 is applied vertically down. Consider the following statements for this situation:

    Statement I: If $F_1 > F_2$, the crate with move to the right.
    Statement II: The net force acting on the crate is the vector sum of F_1, F_2, & F_3.
    Statement III: If $F_3 > F_1 + F_2$, the crate will move upward.

    Which statement(s) accurately describe(s) the result of the forces acting on the crate?
    a. I only b. II only c. I & II only d. III only e. II & III only

10. A rock is thrown vertically upward with an initial velocity of 20.0 m/s. What is the maximum height the rock will reach, assuming no air resistance?
    a. 10.0 m b. 20.0 m c. 40.0 m d. 80.0 m e. 100 m

DIVISION 1 STUDENTS

Continue

Answer questions #11 through #40.

DIVISION 2 STUDENTS

START HERE

Numbers 1 – 10 on your answer sheet should be blank. Your first answer should be for #11.

Treat $g = 10.0\ \frac{m}{s^2}$ for ALL questions.

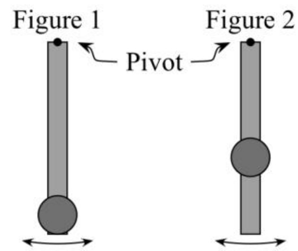
11. Two sound waves have the same frequency. One of the sound waves is traveling in air at 331 $\frac{m}{s}$ and the other is traveling in water at 1450 $\frac{m}{s}$. What is the ratio of the wavelength of the sound in water to the wavelength of sound in air?
    a. 0.228 b. 0.478 c. 1.00 d. 2.09 e. 4.38

12. When they are fishing, pelicans tuck their wings and dive straight down. Assume a pelican starts its dive from a height of 16.0 m above a fish at the surface of the water and cannot change its path once committed. If it takes a fish 0.20 s to perform evasive action, at what minimum height
    must it spot the pelican to escape? Assume the fish is at the surface of the water.
    a. 2.42 m b. 2.94 m c. 3.37 m d. 9.12 m e. 12.6 m

13. A small cart with a mass of 50 g is rolling on a frictionless track with a velocity of +10 $\frac{m}{s}$. It then has a head-on, elastic collision with a stationary cart of mass 100 g. What is the speed of each cart immediately after the collision? The 50-g cart speed is listed first followed by the 100-g cart speed in all choices.
    a. -3.3 $\frac{m}{s}$ and +6.7 $\frac{m}{s}$ b. +3.3 $\frac{m}{s}$ and -6.7 $\frac{m}{s}$ c. -6.7 $\frac{m}{s}$ and +3.3 $\frac{m}{s}$
    d. +6.7 $\frac{m}{s}$ and -3.3 $\frac{m}{s}$ e. +3.3 $\frac{m}{s}$ and +6.7 $\frac{m}{s}$

14. The work of which of the following scientists is most closely associated with the discovery of the constancy of the speed of light?
    a. Albert Michelson and Edward Morley
    b. Christiaan Huygens and Augustin-Jean Fresnel
    c. Ernest Rutherford, Hans Geiger and Ernest Marsden
    d. Heinrich Hertz
    e. Willebrord Snell

15. A pendulum is constructed from a uniform rod pivoted at its top end and a circular disk attached near the free end as shown in Figure 1. Figure 2 shows the same pendulum with the disk now attached closer to the pivot. Use the following statements to determine the resulting change in the period of the pendulum.



<u>Statement 1</u>: The moment of inertia of the pendulum about the pivot decreases.
<u>Statement 2</u>: The torque exerted by gravity on the pendulum about the pivot decreases.

a. Only statement one is true, resulting in a decreased period of the pendulum.
b. Only statement two is true, resulting in an increased period of the pendulum.
c. Both statements are true, resulting in a decreased period of the pendulum.
d. Both statements are true, resulting in no change in the period of the pendulum.
e. Both statements are true, resulting in an increased period of the pendulum.

16. Which recent experiment in physics has provided further evidence supporting the existence of dark matter?
a. Observation of gravitational lensing effects around a distant galaxy cluster.
b. Detection of high-energy neutrinos from a distant astrophysical source.
c. Measurement of the cosmic microwave background radiation with unprecedented precision.
d. Discovery of a new particle with properties consistent with those predicted for dark matter.
e. Detection of gamma-ray bursts from the collision of two neutron stars.

17. At a construction site, a bulldozer drags a log weighing 500 N along a rough, horizontal surface. The cable attached to the log makes an angle of 30.0° with the ground. The coefficient of static friction between the log and the ground is 0.500. What minimum tension is required in the cable for the log to begin to move?
a. 125 N　b. 224 N　c. 289 N　d. 500 N　e. 577 N

18. A 432-Hz tuning fork is the lowest frequency tuning fork that can produce resonance when held over one end a certain plastic tube open at both ends. When one end of this tube is closed, which of the following tuning fork frequencies would produce resonance when held over the open end?
a. 133 Hz　b. 288 Hz　c. 720 Hz　d. 1080 Hz　e. 1296 Hz

19. Halley's Comet was last visible on Earth in 1986 and will be visible again in 2061. As it travels on its elliptical orbit around the sun, the speed of Halley’s Comet…
a. is constant.
b. increases as it nears the Sun.
c. decreases as it nears the Sun.
d. is zero at two points in the orbit.
e. can't be determined without more observations.

Questions 20-22 are based on the following situation: A bicycle and its rider have a combined mass of 80.0 kg. The cyclist can coast down a 6.0° hill, and because of air resistance, they are limited to a constant speed of 6.0 $\frac{km}{hr}$. The vertical height of the hill is 120 m.

20. What total distance does the cyclist ride to climb this hill?
    a. 1024 m b. 1042 m c. 1124 m d. 1142 m e. 1148 m

21. How much work against gravity must the cyclist do to climb this hill?
    a. 800 J b. 1200 J c. 9600 J d. 12,000 J e. 96,000 J

22. If each complete revolution of the pedals moves the bike 4.9 m along its path uphill, calculate the average force that must be exerted on the pedals, tangent to their circular path. Neglect work done by friction and other losses. The pedals turn in a circle of diameter 34 cm.
    a. 383 N b. 410 N c. 234 N d. 518 N e. 449 N

23. A solid, uniform disk and a solid, uniform sphere are placed on a ramp where they can roll without slipping. The disk is released a distance *d* from the bottom of the ramp and achieves a center-of-mass speed *v* upon reaching the bottom. From what distance (also measured from the bottom of the ramp) should the sphere be released to attain the same center-of-mass speed *v* at the bottom?
    a. $\frac{1}{5}d$ b. $\frac{9}{10}d$ c. $\frac{14}{15}d$ d. $\frac{5}{4}d$ e. $\frac{5}{3}d$

24. An ideal gas undergoes an isothermal process. Which of the following statements about the change in internal energy (ΔU) for the gas and heat (Q) is true during this process?
    a. ΔU is zero, and Q is zero.
    b. ΔU is zero, and Q is not zero.
    c. ΔU is not zero, and Q is zero.
    d. ΔU is not zero, and Q is not zero, but they are not equal.
    e. ΔU is not zero, and Q is not zero, and they are equal.

25. An Atwood's machine has two masses m_1 and m_2 connected by a light string passing over a pulley. If m_1=5kg and m_2=7kg, and the pulley has a radius of 0.1m, what is the tension in the string?
    a. 20.2 N b. 58.4 N c. 81.7 N d. 120.0 N e. 140.0 N

26. A 2.0-kg mass suspended from a vertical spring stretches it a distance of 5.0 cm. The mass is then pulled down a distance of 10 cm and released. What is the frequency of oscillation?
    a. 0.113 Hz b. 2.25 Hz c. 3.11 Hz d. 0.159 Hz e. 1.59 Hz

27. Mars has a mass of 6.46 x 10^{23} kg and a radius of 3.39 x 10^{6} m. How much would a 65-kg person weigh on Mars?
    a. 122 N b. 198 N c. 244 N d. 416 N e. 650 N

28. A person with a mass *m*, falls from a height of *h* onto a crash mat. The speed of the person when they reach the mat is equal to:
    a. $\sqrt{(2gh)}$ b. $\frac{1}{h}\sqrt{2g}$ c. $2gh$ d. $2\sqrt{gh}$ e. $\frac{1}{\sqrt{2gh}}$

29. When an inelastic collision occurs, the total kinetic energy of the colliding bodies…
    a. increases.
    b. decreases.
    c. remains constant.
    d. decreases then increases.
    e. increases then decreases.

30. A submarine emits a sonar signal to detect the distance to, and velocity of, a second nearby submarine. Which pair of wave behaviors is most closely associated with these two measurements?
    a. Absorption and Interference
    b. Diffraction and Refraction
    c. Dispersion and Polarization
    d. Reflection and Doppler Effect
    e. Refraction and Resonance

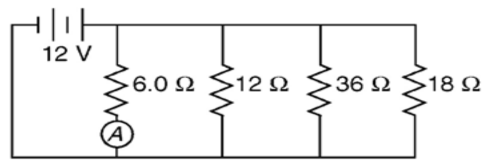
31. A 2-cm thick wall separates two rooms with temperatures of 20 ^{o}C and 10 ^{o}C respectively. The wall has a thermal conductivity of 0.1 $\frac{W}{(m)(K)}$ and a surface area of 10 m^2. What is the rate of heat transfer through the wall?
    a. 50 W b. 250 W c. 500 W d. 1000 W e. 5000 W

32. It is determined that a 500 mF capacitor loses half its remaining charge every second. If, after 5.0 s, its charge is q, what was its initial charge?
    a. $2q$ b. $4q$ c. $8q$ d. $16q$ e. $32q$

33. A top-fuel dragster starts from rest and accelerates at +17.0 $\frac{m}{s^2}$ for 402 m. A parachute then opens behind the dragster to slow it down with an acceleration of -6.10 $\frac{m}{s^2}$. How fast is the dragster moving 350 m after the parachute opens?
    a. 86.9 $\frac{m}{s}$ b. 88.9 $\frac{m}{s}$ c. 96.9 $\frac{m}{s}$ d. 98.9 $\frac{m}{s}$ e. 102.9 $\frac{m}{s}$

34. The relativistic equations for time dilation, length contraction, momentum, and energy are accurate…
    a. at typical low speeds only.
    b. at speeds near the speed of light only.
    c. at all speeds up to the speed of light.
    d. at the speed of light only.
    e. at speeds above the speed of light only.

35. An electrical circuit is constructed with a battery and four resistors as shown in the diagram at the right. What is the current measured by the ammeter shown in the diagram?



a. 2 A   b. 3 A   c. 4 A   d. 5 A   e. 6 A

36. A beaker is filled with 800 mL of water. A wooden cylinder will be placed into the beaker. If the wood's density is 800 $\frac{kg}{m^3}$, what mass cylinder will raise the water level to the beaker's maximum volume of 1000 mL?

a. 100 g   b. 160 g   c. 200 g   d. 250 g   e. 360 g

37. A small sphere of mass *m* is attached to one end of a light string of length *L* with the other end of the string attached to a fixed point. The ball is moving at a constant speed *v* in a horizontal circle of radius *r* such that the string makes an angle θ with the vertical. Given that the tension in the string is *T*, what is the correct expression for the object's speed *v*?

a. $v = \sqrt{\frac{TLsin\theta}{m}}$ b. $v = \sqrt{\frac{gsin\theta}{L}}$ c. $v = \sqrt{\frac{TL}{mg}}$

d. $v = \sqrt{\frac{mg}{TL}}$ e. $v = \sqrt{\frac{2TL}{mg}}$

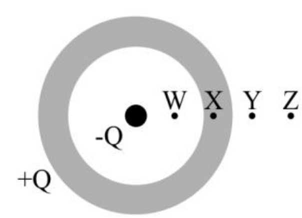
38. Two objects both move and uniformly accelerate to the right. At time *t*=0, the objects are at the same initial position, but Object 1 has an initial speed twice that of Object 2. Object 1 has one-half the acceleration of Object 2. After some time, *T*, the velocity of the two objects is the same. What is the ratio of the distance traveled in this time, *T*, by Object 2 to that traveled by Object 1?

a. 5:6   b. 4:5   c. 3:4   d. 2:3   e. 1:2

39. An increase in the average speed of the molecules of a gas confined in a rigid cylinder will correspond to an…

a. increase in the temperature of the gas only.
b. increase in the pressure of the gas only.
c. increase in both the temperature and the pressure of the gas.
d. increase in the temperature of the gas and a decrease in its pressure.
e. increase in the pressure of the gas and a decrease in its temperature.

40. A metal spherical shell with a charge +*Q* surrounds a point charge with a charge –*Q*. Which of the following correctly ranks the electric potentials at the lettered points (W, X, Y and Z). Assume $V \to 0$ as $r \to \infty$.



a. $V_W < V_X < V_Y < V_Z$
b. $V_W = V_X < V_Y = V_Z$
c. $V_W < V_X < V_Z < V_Y$
d. $V_Z < V_W = V_Y < V_X$
e. $V_W < V_X = V_Y = V_Z$

DIVISION 1 STUDENTS

STOP HERE

Your last answer should be for #40. Numbers 41-50 should remain blank for Division 1 students.

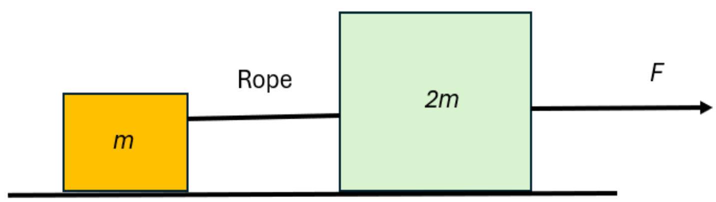
DIVISION 2 STUDENTS

CONTINUE

Answer questions #41 through #50.

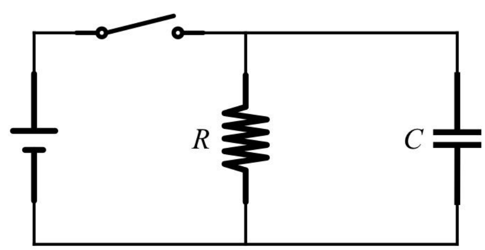
Treat $g = 10.0\ \frac{m}{s^2}$ for ALL questions.

41. A rope is used to connect two boxes, one with a mass of *m* and the other with a mass of *2m* as shown in the diagram at the right. The boxes are resting on a smooth surface. A force *F* is then applied to the larger box. What is the tension in the connecting rope?



a. 3F   b. F   c. F/2   d. F/3   e. 2F

42. In the circuit shown, the voltage source, switch, capacitor and connecting wires have no resistance. The switch is closed until the circuit achieves steady state, at which point the switch is opened. Which of the following statements about the potential differences after the switch is opened is true.



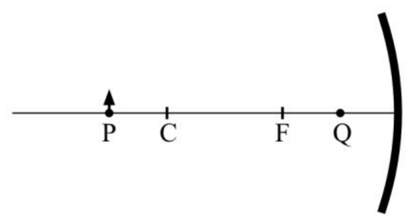
a. The potential differences across the resistor and capacitor instantly become zero.
b. The potential differences across the resistor and capacitor are equal at all times.
c. The potential difference across the resistor increases, while the potential difference across the capacitor decreases.
d. The potential difference across the resistor instantly becomes zero, while the potential difference across the capacitor remains unchanged.
e. The potential difference across the resistor remains unchanged, while the potential difference across the capacitor instantly becomes zero.

43. The temperature of a black body is increased. The wavelength of electromagnetic radiation that is emitted with the greatest intensity will…
    a. shift toward longer wavelength.
    b. shift toward short wavelength.
    c. remains the same.
    d. shift toward shorter then longer wavelength.
    e. shift toward longer then shorter wavelength.

44. When NASA began conducting test flights for the space shuttle, they used a "glider" that had a mass of 980 kg (including pilot). This glider was launched horizontally at 500 $\frac{km}{hr}$ from a height of 3500 m. The glider eventually landed at a speed of 200 $\frac{km}{hr}$. What was the average force of air resistance exerted on the glider if it came in at a constant angle of 10° to the Earth?
    a. 1956 N   b. 2010 N   c. 2056 N   d. 2090 N   e. 3016 N

45. The Moon orbits the Earth on a nearly circular orbit with a period, *T*, of 27.3 days. The radius of orbit is 3.84 x 10^5 km. What is the acceleration of the Moon toward the Earth?
    a. 1.72 x 10^{-3} $\frac{m}{s^2}$
    b. 1.92 x 10^{-3} $\frac{m}{s^2}$
    c. 2.22 x 10^{-3} $\frac{m}{s^2}$
    d. 2.52 x 10^{-3} $\frac{m}{s^2}$
    e. 2.72 x 10^{-3} $\frac{m}{s^2}$

46. A small object is placed in front of a concave mirror and to the left of the center of curvature at point P in the picture. As the object is moved from point P to point Q, the size of the image produced will …



    a. always decrease.
    b. always increase.
    c. first decrease and then increase.
    d. first increase and then decrease.
    e. first increase, then decrease and then increase again.

47. Each of the two blades in the rotor of a helicopter is 6.4 m long, has a mass of 230 kg, and is attached at one end to the rotor hub at the center. The blades are rotating with a frequency of 401 $\frac{rev}{min}$. What is the total rotational kinetic energy of the spinning blades?
    a. 1.40 x 10^6 J
    b. 2.77 x 10^6 J
    c. 4.14 x 10^6 J
    d. 5.54 x 10^6 J
    e. 9.91 x 10^6 J

48. A drop of liquid is spherical and has a diameter of 2.0 mm. It is given a charge of 2.0×10^{-15} C. This charged drop then combines with an identical uncharged drop and the two form one single drop. What is the electric potential at the surface of newly formed drop?
   a. 0.0143 V b. 0.0244 V c. 0.0286 V d. 0.0418 e. 0.0506 V

49. Wire *A* has a length of 2.0 m, a mass of 4.0 g, and it carries 10 A of current. The wire, which is parallel to the floor and can only move vertically, is placed above wire *B* that is carrying 15 A of current in the opposite direction. What separation distance between the two wires will allow the weight of wire *A* to be supported by magnetic force?
   a. 1.25 mm b. 1.50 mm c. 1.75 mm d. 2.00 mm e. 2.25 mm

50. A gas undergoes radioactive decay with time constant τ. A sample of 10000 particles is put into a container. After one time constant has passed, the experimenter adds another 10000 particles into the container. How much time passes from the addition of the particles until the container of gas reaches 10000 total particles again?
   a. $(0.313)\ \tau$ b. $(0.500)\ \tau$ c. $(0.693)\ \tau$ d. τ e. 2τ