Solutions for the OAPT Physics Contest 2004

Foreword:

The following solutions were prepared by Rolly Meisel, rollym@vaxxine.com. Comments or errors are solicited. Also solicited are **contributions** for the **2005 OAPT Physics Contest**. We are looking for questions that match the expectations of the Ontario Grade 12U physics course. Questions that require long strings of calculations or substitution into memorized formulas are less effective than those that require an insight into physical principles and an understanding of the concepts.

Forces and Motion

1) An arrow is shot straight up with an initial speed of 10 m/s. How long does it take the arrow to reach its maximum height? Ignore air resistance.

A) 0.50 s B) 1.0 s C) 2.0 s D) 9.8 s E) 20 s

Solution

2) A cyclist is traveling west at 9.0 m/s. A rollerblader is 6.0 km directly ahead of the cyclist and traveling west at 5.0 m/s. How long will it take for the cyclist to catch up to the rollerblader?

A) 1.5 s B) 2.3×10^2 s C) 4.3×10^2 s D) 5.3×10^2 s E) 1.5×10^3 s

Solution

3) A rabbit hops at 60 m/min for 2.0 min due east. It then reverses its direction and hops due west at 120 m/min for 1.0 min. What is the average speed of the rabbit?

A) 0 m/min B) 40 m/min C) 60 m/min D) 80 m/min E) 90 m/min

Solution

4) A boy is sitting in his tree house and observes a falling walnut passing from the top to the bottom of his window. The window is 2.5 m tall and it takes 0.43 s for the walnut to pass the window. How far is the top of the window from the squirrel above it that dropped the walnut? Ignore air resistance.

A) 0.29 m B) 0.58 m C) 0.70 m D) 2.5 m E) 3.2 m

Solution

5) You throw your pen straight up in your physics classroom. Ignore air resistance. Which statement concerning the net force acting on the pen at the top of its path is true?

A) The net force is instantaneously equal to zero. B) The direction of the net force changes from up to down.
C) The net force is greater than the weight of the pen. D) The net force is equal to the weight of the pen.
E) The net force is less than the weight of the pen, but greater than zero.

Solution

6) A pail filled with sand has a total mass of 60 kg. A crane is lowering it such that it has an initial downward acceleration of 1.5 m/s^2. A hole in the pail allows sand to leak out. If the force exerted by the crane on the pail does not change, what mass of sand must leak out before the downward acceleration decreases to zero?

A) 9.2 kg B) 20 kg C) 40 kg D) 51 kg E) 60 kg

Solution

Energy, Work and Power

7) A skier wearing special frictionless skies slides straight down a hill of vertical height 24 m inclined at 35° to the horizontal. If her initial velocity is zero, and air resistance is negligible, what is her speed at the bottom of the ramp?

A) 5.6 m/s B) 8.0 m/s C) 9.8 m/s D) 20 m/s E) 22 m/s

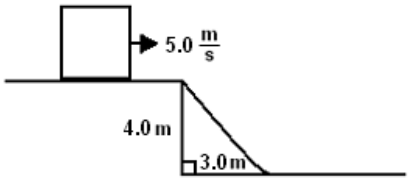
Solution

8) A baseball pitcher accelerates a ball in a horizontal plane from rest to a speed of 40 m/s. If the ball has a mass of 0.20 kg, and pitcher's arm is 0.80 m long, find the work done by the pitcher on the ball.

A) 1.6 J B) 5.6 J C) 8.0 J D) 1.6×10^2 J E) 1.6×10^3 J

Solution

9) A box slides along a horizontal frictionless surface at a constant speed of 5.0 m/s. The box then slides smoothly down a frictionless incline and onto a second frictionless horizontal surface without tipping or rolling as shown in the figure. What is the speed of the box on the second surface?



A) 9.0 m/s B) 9.8 m/s C) 10 m/s D) 14 m/s E) 15 m/s

Solution

10) The energy content of gasoline is 3.6×10^7 J/L. A motor with an efficiency of 20% is needed at full output power of 45 kW for 50.0 minutes. How many litres of gasoline are required to operate the motor for this amount of time?

A) 0.31 L B) 0.38 L C) 1.6 L D) 3.8 L E) 19 L

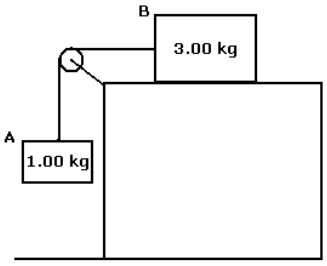
Solution

11) A 55.0 kg diver strikes the water perpendicularly at a speed of 7.7 m/s and experiences an average retarding force of 1315 N. What is the maximum depth the diver's hands will attain?

A) 1.2 m B) 2.1 m C) 2.4 m D) 3.2 m E) 4.2 m

Solution

12) Two masses are connected as shown in the figure. The system is released from rest and mass A falls to the floor through a distance of 1.0 m. The table and pulley are frictionless. What is the kinetic energy of mass A just before it reaches the floor?



A) 2.4 J B) 5.0 J C) 9.7 J D) 39 J E) 70 J

Solution

Waves and Sound

13) Two toy ducks are floating in a lake 12 m apart. They are bobbing up and down 25 cm above and below the lake level with a period of 2 seconds. Find the speed of the waves.

A) 1.5 m/s B) 2.0 m/s C) 3.0 m/s D) 6.0 m/s
E) There is not enough information to determine a correct answer.

Solution

14) Two loudspeakers are placed about 70 centimeters apart on a desk such that they face west. Each speaker is emitting sound with the same frequency and with the same intensity. You are asked to slowly walk north in front of the loudspeakers. As you do so, you hear alternate soft and loud sounds. This effect is best explained by

A) reflection B) refraction C) dispersion D) interference E) diffraction

Solution

15) The speed of sound in air at 0°C is 332 m/s, and increases by 0.60 m/s for every degree Celsius that the temperature rises. A piano tuner strikes a key which vibrates at 1024 Hz in a room with a temperature of 20°C. A beat frequency of 26 Hz results when a tuning fork and the key are struck simultaneously: A possible wavelength of the note produced by the tuning fork is

A) 30 cm. B) 33 cm. C) 36 cm. D) 64 cm. E) 70 cm.

Solution

16) An observer was standing on a railroad platform. A train leaving the station blew its whistle at 500 Hz. A train at rest in the station joined in with the same frequency. The observer heard

A) beats at 0 Hz. B) beats at more than 0 Hz but less than 500 Hz. C) beats at 500 Hz.
D) beats at more than 500 Hz. E) nothing. The sounds will cancel each other.

Solution

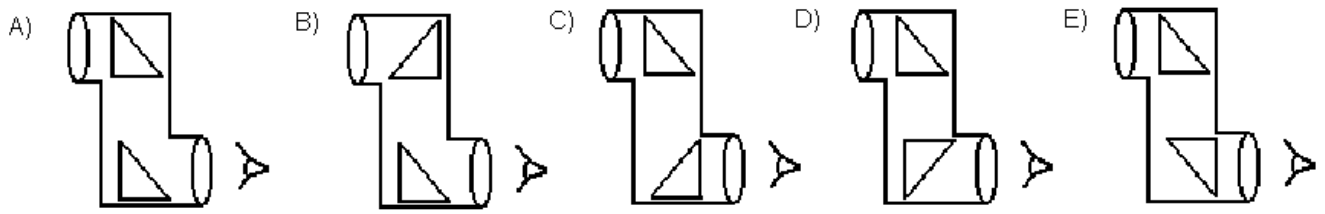
17) An air column open at one end only is increased in length The air column first resonates with a given tuning fork when the length of the air column reaches 20 cm. The next two consecutive lengths that will resonate with the same tuning fork will measure

A) 30 cm and 40 cm. B) 40 cm and 60 cm. C) 60 cm and 90 cm. D) 60 cm and 100 cm. E) 80 cm and 100 cm.

Solution

Light and Geometric Optics

18) Two prisms are used to make a periscope. Which of the following is the correct arrangement?



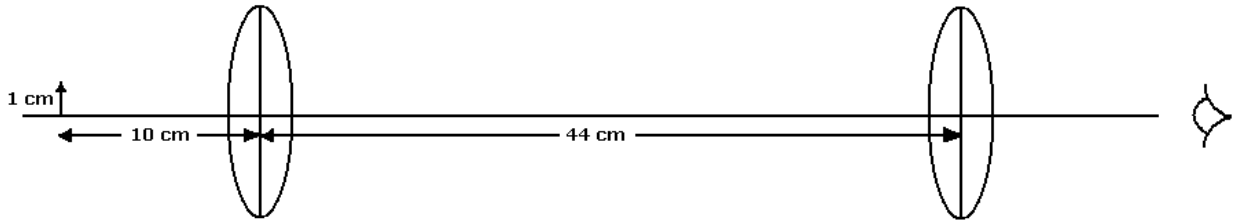
Solution

19) A fiber optic line is composed of a core with an index of refraction of 1.61 and cladding with an index of 1.38. The angle θ is the angle of incidence for a ray of light travelling in the core and incident on the core-cladding interface. Which one of the following relations best describes the angle θ that will result in total internal reflection within the fiber optic line?

A) $\theta < 59^\circ$ B) $\theta > 59^\circ$ C) $\theta < 31^\circ$ D) $\theta > 31^\circ$ E) $0 < \theta < 90^\circ$

Solution

20) Determine the size and orientation of the image formed by the lens system shown. Each lens has a focal length of 8 cm. The diagram is not necessarily drawn to scale.

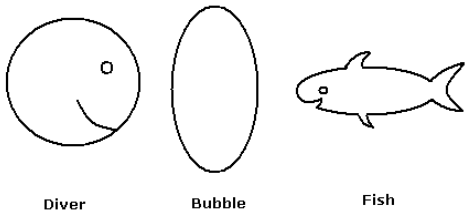


A) 4 cm, erect B) 4 cm, inverted C) 8 cm, erect D) 8 cm, inverted E) No image is formed

Solution

21) A fish sees the smiling face of a scuba diver through a bubble of air between them, as shown. Compared to the face of the diver, the image seen by the fish will be

A) smaller and erect B) smaller and inverted C) larger and erect
D) larger and inverted E) the same size and erect



Solution

22) A small candle is 1.00 m from a screen. A lens of focal length +10.0 cm is placed between the candle and the screen. There are two positions for the lens that will result in a sharp image of the candle on the screen. Find the distance between these two positions.

A) 11.3 cm B) 52.2 cm C) 77.5 cm D) 88.7 cm E) 91.4 cm

Solution

Electricity and Magnetism

23) A pair of ideal identical 12 V batteries, each storing 2×10^5 J of energy, are connected in parallel and provide a total constant current of 70 A. How long will the batteries last?

A) 4 min B) 8 min C) 12 min D) 24 min E) 70 min

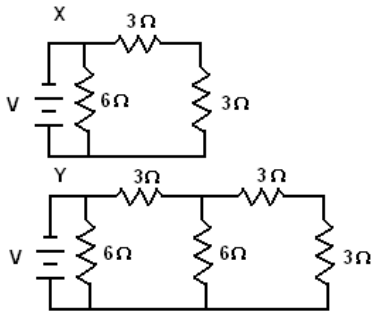
Solution

24) Seven identical Christmas tree lights when connected in series to a 120 V source each produce 8.0 W. What is the resistance of each bulb?

A) 37 Ω B) 56 Ω C) 1.4×10^2 Ω D) 2.6×10^2 Ω E) 1.8×10^3 Ω

Solution

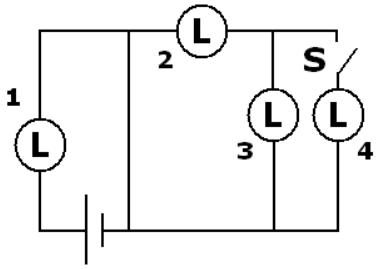
25) Consider the resistor networks X and Y shown in the diagram.



A) Network X has the lowest equivalent resistance and will draw the most current.
B) Network X has the highest equivalent resistance and will draw the most current.
C) Network Y has the lowest equivalent resistance and will draw the most current.
D) Network Y has the highest equivalent resistance and will draw the most current.
E) Both networks have the same equivalent resistance and will draw the same current.

Solution

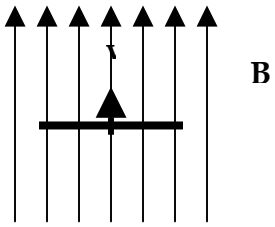
26) A circuit is connected as shown. All light bulbs are identical. When the switch **S** in the circuit is closed, which bulb(s) other than **4** become(s) brighter?



A) None B) 1 only C) 2 only
D) 3 only E) 2 and 3 only

Solution

27) A horizontal length of a wire copper moves up with a steady velocity **v** in the direction of a constant vertical magnetic field **B**, as shown in the diagram. Which one of the following describes the induced charges on the ends of the wire?



	Left End	**Right End**
A)	Positive	Negative
B)	Negative	Positive
C)	Negative	Zero
D)	Zero	Negative
E)	Zero	Zero

Solution

28) A direct current of 10 A at 120 V is present in the primary coil of a transformer. The secondary coil has twice as many turns as the primary. The voltage across the secondary coil is

A) 0 V B) 60 V C) 120 V D) 240 V E) 1200 V

Solution

Nobel Prize/Current Events

29) During the summer of 2003 the power went out in Ontario. Assuming a total loss of 24 hours, and a price of $0.043/kWh, estimate the order of magnitude of the money lost by Ontario Power Generation.

A) $\$10^4$ B) $\$10^5$ C) $\$10^7$ D) $\$10^9$ E) $\$10^{11}$

Solution

30) The Nobel Prize in physics for 2003 was awarded for contributions to the theory of superconductors and superfluids. Which of the following statements is NOT correct?

A) Superconductivity was first observed in mercury about 100 years ago.
B) If superfluid helium is put in an open container it will travel up the sides of the container and travel out over the top.
C) Type-1 superconductors exhibit very strong diamagnetism and are explained by the famous BCS theory which suggests that electrons team up in pairs.
D) Copper, silver and gold are not only excellent conductors but also superb superconductors.
E) In type-2 superconductors, superconductivity and magnetic flux can co-exist allowing for many technical applications.

Solution

Solutions

1) Solution

At maximum height, v = 0 m/s.

$$v = u + at$$

$$0 = 10\,\frac{\text{m}}{\text{s}} - 9.8\,\frac{\text{m}}{\text{s}^2} \times t$$ The answer is (B) 1.0 s.

$$t = 1.0\ \text{s}$$

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2) Solution

The cyclist is catching up to the rollerblader at a relative speed of 4.0 m/s. The gap is 6000 m.

$$t = \frac{d}{v}$$

$$= \frac{6.0 \times 10^3 \text{m}}{4.0\,\frac{\text{m}}{\text{s}}}$$ The answer is (E) 1.5 x 10^3 s.

$$= 1.5 \times 10^3\ \text{s}$$

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3) Solution

$$d_1 = v_1 t_1$$

$$= 60\,\frac{\text{m}}{\text{min}} \times 2.0\ \text{min}$$

$$= 1.2 \times 10^2\ \text{m}$$

$$d_2 = v_2 t_2$$

$$= 120\,\frac{\text{m}}{\text{min}} \times 1.0\ \text{min}$$

$$= 1.2 \times 10^2\ \text{m}$$

$$v_{av} = \frac{d}{t}$$

$$= \frac{1.2 \times 10^2\ \text{m} + 1.2 \times 10^2\ \text{m}}{2.0\ \text{min} + 1.0\ \text{min}}$$

$$= 80\,\frac{\text{m}}{\text{min}}$$

The answer is (D) 80 m/min.

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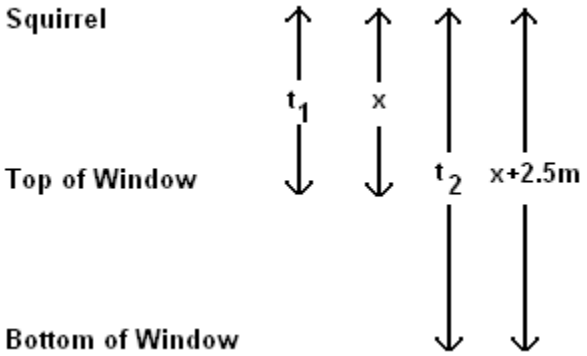
4) Solution



$$t_2 - t_1 = 0.43$$

$$2.5 = \frac{1}{2}g\left(t_2^2 - t_1^2\right)$$

$$2.5 = \frac{1}{2}g\left(t_2 - t_1\right)\left(t_2 + t_1\right)$$

$$2.5 = \frac{1}{2}g(0.43)(2t_1 + 0.43)$$ The answer is (C)

$$t_1 = 0.38\text{s}$$

$$x = \frac{1}{2}gt_1^2$$

$$= 0.70 \text{ m}$$

0.70 m.

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5) Solution

The pen is in free fall. The only force acting on it is its own weight. The answer is (D) The net force is equal to the weight of the pen.

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6) Solution

Free Body Diagram at Start

$$m_1 g - F_c = m_1 a$$

$$F_c = m_1\left(g - a\right)$$

Free Body Diagram When a=0

$$F_c - m_2 g = 0$$

$$F_c = m_2 g$$ The answer is (E) 9.2 kg.

$$m_1\left(g - a\right) = m_2 g$$

$$m_2 = \frac{m_1\left(g - a\right)}{g}$$

$$= 50.8 \text{ kg}$$

$$\Delta m = 9.2\text{kg}$$

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7) Solution

Since there is no friction, the incline angle is irrelevant.

$$\frac{1}{2}mv^2 = mgh$$

$$v = \sqrt{2gh}$$ The answer is E) 22 m/s.

$$= 22\,\frac{\text{m}}{\text{s}}$$

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8) Solution

$$W = \Delta E_k$$

$$= \frac{1}{2}mv^2$$

$$= \frac{1}{2}(0.20\ \text{kg})\left(40\ \frac{\text{m}}{\text{s}}\right)^2$$ The answer is D) 1.6×10^2 J.

$$= 1.6\times10^2\ \text{J}$$

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9) Solution

$$\frac{1}{2}mv_1^2 + mgh = \frac{1}{2}mv_2^2$$

$$v_2 = \sqrt{v_1^2 + 2gh}$$ The answer is C) 10 m/s.

$$= 10\ \frac{\text{m}}{\text{s}}$$

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10) Solution

$$E = Pt$$

$$= 1.35\times10^8\ \text{J}$$

$$V = \frac{1.35\times10^8\ \text{J}}{3.6\times10^7\ \frac{\text{J}}{\text{L}}}$$

$$= 3.75\ \text{L}$$

Since the motor is 20% efficient, five times as much gasoline is needed. The answer is E) 19 L.

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11) Solution

$$Fd = \frac{1}{2}mv^2 + mgd$$

$$d = \frac{mv^2}{2(F - mg)}$$

$$= 2.1 \text{ m}$$

The answer is B) 2.1 m.

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12) Solution

$$m_A gh = \frac{1}{2}(m_A + m_B)v^2$$

$$v = \sqrt{\frac{(2m_A gh)}{(m_A + m_B)}}$$

$$= 2.2 \ \frac{\text{m}}{\text{s}}$$

The answer is A) 2.4 J.

$$E_{kA} = \frac{1}{2}m_A v^2$$

$$= 2.4 \text{ J}$$

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13) Solution

We do not know how many waves are between the ducks. The answer is E) There is not enough information to determine a correct answer.

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14) Solution

Loud areas are areas of constructive interference. Soft areas are areas of destructive interference. The answer is D) interference.

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15) Solution

$$v = 332 \ \frac{\text{m}}{\text{s}} + 20 \times 0.6 \ \frac{\text{m}}{\text{s}}$$

$$= 344 \ \frac{\text{m}}{\text{s}}$$

The beat frequency is 26 Hz. Therefore, the possible frequencies of the tuning forks are 1024 + 26 = 1050 Hz and 1024 – 26 = 998 Hz. The corresponding wavelengths are, respectively, 0.33 m and 0.34 m. The only matching answer is B) 33 cm.

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16) Solution

Since the train is leaving the station, the Doppler Shift predicts that the observer will hear a frequency of less than 500 Hz. This will produce a beat frequency between 0 Hz and 500 Hz. The answer is B) beats at more than 0 Hz but less than 500 Hz.

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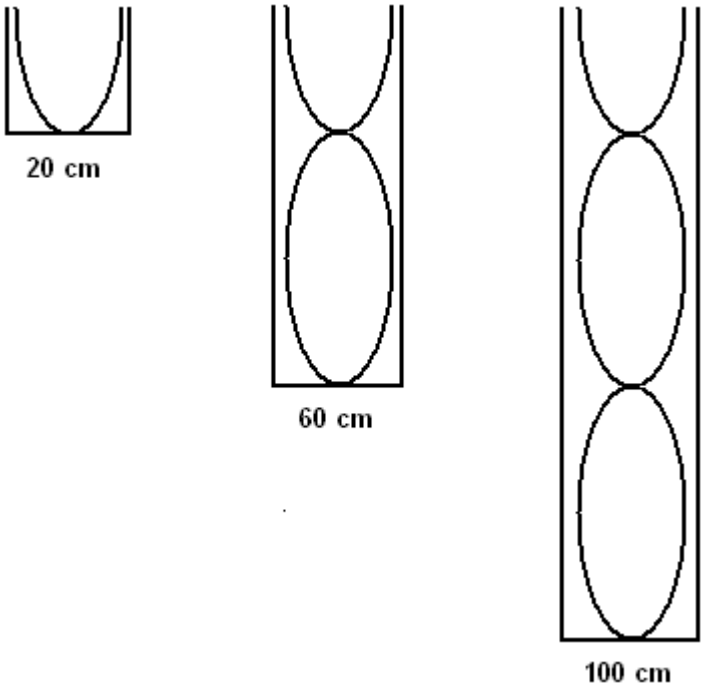
17) Solution



The answer is D) 60 cm and 100 cm.

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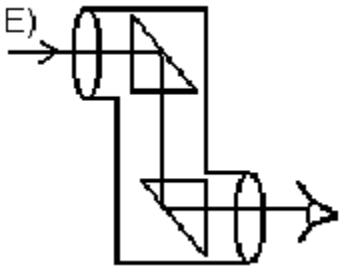
18) Solution



Use the principle of total internal reflection. The answer is (E).

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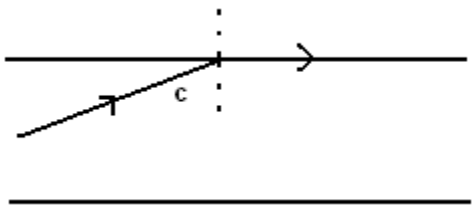
19) Solution



$$\frac{\sin c}{\sin 90^\circ} = \frac{1.38}{1.61}$$

$$c = 59^\circ$$

For angles greater than 59º, total internal reflection occurs. The answer is B) θ > 59º.

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20) Solution

For the first lens:

$d_o = 10$ cm

$h_o = 1$ cm

$f = 8$ cm

$$\frac{1}{d_o} - \frac{1}{d_i} = \frac{1}{f}$$

$$\frac{1}{10} - \frac{1}{d_i} = \frac{1}{8}$$

$d_i = -40$ cm

$$\frac{d_o}{d_i} = \frac{h_o}{h_i}$$

$h_i = -4$ cm

For the second lens:

$d_o = 4$ cm

$h_o = -4$ cm

$f = 8$ cm

$$\frac{1}{d_o} - \frac{1}{d_i} = \frac{1}{f}$$

$$\frac{1}{4} - \frac{1}{d_i} = \frac{1}{8}$$

$d_i = 8$ cm

$$\frac{d_o}{d_i} = \frac{h_o}{h_i}$$

$h_i = -8$ cm

The answer is D) 8 cm, inverted.

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21) Solution

The bubble behaves like a diverging lens, since the index of refraction of the air in the bubble is less than the index of refraction of the water. The answer is A) smaller and erect.

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22) Solution

$$d_o + d_i = 100 \text{ cm}$$

$$\frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{f}$$

$$\frac{1}{d_o} + \frac{1}{100 - d_o} = \frac{1}{10}$$

$$\frac{d_o + 100 - d_o}{d_o(100 - d_o)} = \frac{1}{10}$$

$$d_o^2 - 100 d_o + 1000 = 0$$

Use the quadratic formula to find the two solutions, and subtract.

The answer is C) 77.5 cm.

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23) Solution

The current through each battery is 35 A. Use $E = VIt$ and solve for t. The answer is B) 8 min.

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24) Solution

The total power consumption of the string is 56 W. Using $P = \frac{V^2}{R}$, calculate the resistance of the string as 257 Ω. Since they are in series, the resistance of each bulb is 37 Ω. The answer is (A).

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25) Solution

Consider network Y. The two 3 Ω resistors at the right add up to 6 Ω. The parallel connection with the 6 Ω resistor results in an effective resistance of 3 Ω. Hence, circuit Y is equivalent to circuit X. The answer is E) Both networks have the same equivalent resistance and will draw the same current.

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26) Solution

Bulbs 2, 3 and 4 are short-circuited by the wire just to the right of the power supply. The potential drop across these bulbs is 0 V, regardless of the position of the switch. They will never light up. The answer is A) None.

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27) Solution

Since the direction of motion and the magnetic field are in the same direction, the force on the electrons will be 0 N. The answer is (E).

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28) Solution

Since the primary coil has a direct current of 10 A at 120 V, the voltage across the secondary coil is 0 V. A transformer only works if the current in the primary coil is changing. The answer is A) 0 V.

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29) Solution

The demand for electrical power in Ontario is about 20 000 MW. The cost can be estimated:

$$C = 20\,000\,000 \times 24 \times 0.043$$
$$\sim \$2 \times 10^7$$

To an order of magnitude, the answer is (C) $\$10^7$.

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30) Solution

The correct answer is D). Information on Nobel Prize winners in physics can be found in many places. One such is

http://almaz.com/nobel/physics/physics.html

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