WYSE Academic Challenge
2015 Sectional Physics Exam
SOLUTION SET

1. **Correct answer: D**

Note: [*quantity*] denotes: units of *quantity*

a) $\dfrac{[momentum]}{[mass]} = \dfrac{[mv]}{[m]} = \dfrac{[mass][length]/[time]}{[mass]} = [length]/[time]$

b) $\dfrac{[momentum]}{[force]} = \dfrac{[mv]}{[ma]} = \dfrac{[mass][length]/[time]}{[mass][length]/[time]^2} = [time]$

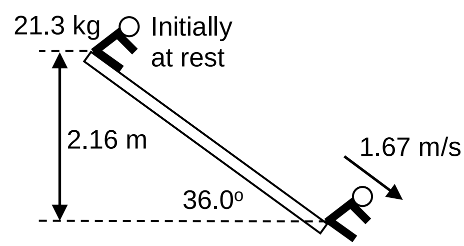
c) $\dfrac{[energy]}{[work]} = 1$

d) $\dfrac{[power]}{[energy]} = \dfrac{[energy]/[time]}{[energy]} = \dfrac{1}{[time]}$ (correct answer)

e) $\dfrac{[energy]}{[force]} = \dfrac{[force][length]}{[force]} = [length]$

2. **Correct answer: B**

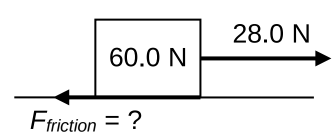
Using work = change in energy of the child-Earth system:



$$\begin{aligned}
W_{friction} &= E_{f,sys} - E_{i,sys} \\
&= GPE_f + KE_f - GPE_i - KE_i \\
&= mgy_f + \frac{1}{2}mv_f^2 - mgy_i - \frac{1}{2}mv_i^2 \\
&= mg(0) + \frac{1}{2}mv_f^2 - mgy_i - \frac{1}{2}m(0)^2 \\
&= \frac{1}{2}(21.3\text{ kg})(1.67\text{ m/s})^2 - (21.3\text{ kg})(9.80\text{ m/s}^2)(2.16\text{ m}) \\
&= -421\text{ J} \quad \xrightarrow{\textit{magnitude}} \quad 421\text{ J}
\end{aligned}$$

3. **Correct answer: B**

The maximum possible static friction is 42.0 N.



$$\begin{aligned}
f_{static} &\le \mu_s N_F \\
&\le (0.700)(60.0\text{N}) \\
&\le 42.0\text{N}
\end{aligned}$$

Since the applied force is less than 42.0 N, the object will remain at rest with the frictional force equal and opposite to the applied force of 28.0 N. $f_{static} = 28.0\text{N}$

4. **Correct answer: E**

Since the applied force is greater than the maximum static friction of 42.0 N, the object will be moving, and therefore subject to kinetic friction. The object will accelerate according to Newton's 2nd Law.

$$F_{net} = ma = m\frac{(v_f - v_i)}{t} = m\frac{(v_f - 0)}{t}$$

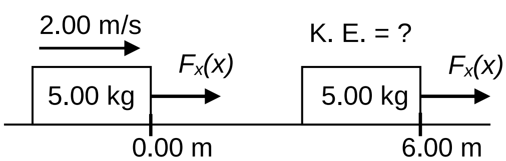
$$v_f = F_{net}\frac{t}{m} = \left(F_{applied} - \mu_k N_F\right)\frac{t}{m}$$

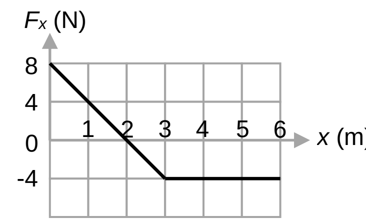
$$= (44.0\,\text{N} - 0.400 \times 60.0\,\text{N})\frac{2.40\,\text{s}}{(60.0/9.80)\,\text{kg}}$$

$$= 7.84\,\text{m/s}$$

5. **Correct answer: A**

Work (= area 'under' a *F* vs. *x* graph) = change in *energy*.





$$Area_{\text{from 0 to 6.m}} = \frac{1}{2}(2.00\,\text{m})(8.00\,\text{N}) + \frac{1}{2}(3.00\,\text{m-}2.00\,\text{m})(-4.00\,\text{N}) + (6.00\,\text{m-}3.00\,\text{m})(-4.00\,\text{N})$$

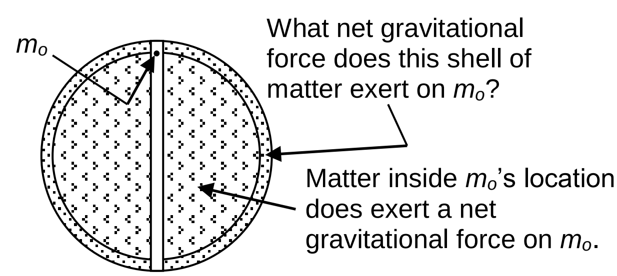
$$= -6.00\,\text{J}$$

$$Area_{\text{from 0 to 6.m}} = -6.00\,\text{J} = \Delta Energy = KE_f - KE_i = KE_f - \frac{1}{2}(5.00\,\text{kg})(2.00\,\text{m/s})^2$$

$$KE_f = 4.00\,\text{J}$$

6. **Correct answer: E**

Only the mass **inside** the radial location of the object contributes to a net gravitational force. The mass outside the object's radial location exerts a net zero force. See a freshman college physics text for a full explanation.



7. **Correct answer: D**

Assign the initial position of the ball to be (x = 0.00, y = 5.80 m)

$$v_{\text{top},y}^2 = v_{i,y}^2 + 2a_y\left(y_{top} - y_i\right)$$

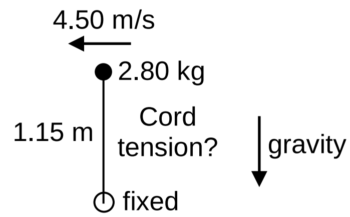
$$0 = (7.30\,\text{m/s})^2 + 2\left(-9.80\,\text{m/s}^2\right)(y_f - 5.80\,\text{m})$$

$$y_{top} = 8.52\,\text{m}$$

8. **Correct answer: C**

$$v_{\text{bottom},y}^2 = v_{i,y}^2 + 2a_y\left(y_{bottom} - y_i\right)$$
$$v_{\text{bottom},y}^2 = \left(7.30\,\text{m/s}\right)^2 + 2\left(-9.80\,\text{m/s}^2\right)\left(0 - 5.80\,\text{m}\right)$$
$$= 166.97\,\text{m}^2/\text{s}^2$$
$$Speed_{bottom} = \sqrt{v_{\text{bottom},x}^2 + v_{\text{bottom},y}^2} = \sqrt{\left(8.50\,\text{m/s}\right)^2 + 166.97\,\text{m}^2/\text{s}^2}$$
$$= 15.5\,\text{m/s}$$

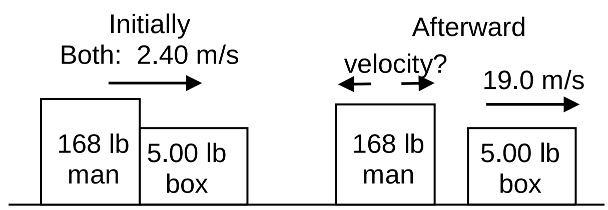
9. **Correct answer: C**



$$F_{net} = ma$$
$$T\left(\boldsymbol{down}\right) + mg\left(\boldsymbol{down}\right) = m\frac{v^2}{R}\left(\boldsymbol{down}\right)$$
$$T = m\left(\frac{v^2}{R} - g\right) = \left(2.80\,\text{kg}\right)\left(\frac{\left(4.50\,\text{m/s}\right)^2}{1.15\,\text{m}} - 9.80\,\text{m/s}^2\right) = 21.9\,\text{N}$$

10. **Correct answer: E**

The momentum of the man-box system is conserved.

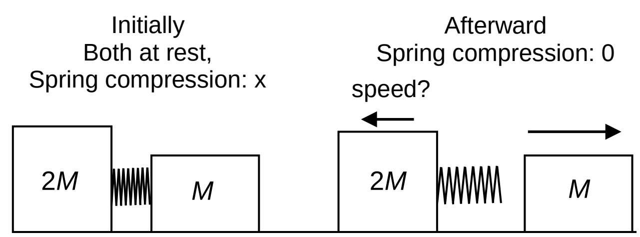


$$m_{man}\boldsymbol{v}_{man,i} + m_{box}\boldsymbol{v}_{box,i} = m_{man}\boldsymbol{v}_{man,f} + m_{box}\boldsymbol{v}_{box,f}$$
$$\left(\frac{168\text{ lb}}{g}\right)\left(2.40\text{ m/s }\boldsymbol{E}\right) + \left(\frac{5.00\text{ lb}}{g}\right)\left(2.40\text{ m/s }\boldsymbol{E}\right) = \left(\frac{168\text{ lb}}{g}\right)\boldsymbol{v}_{man,f} + \left(\frac{5.00\text{ lb}}{g}\right)\left(19.0\text{ m/s }\boldsymbol{E}\right)$$
$$\left(415.2\text{ lb}\cdot\text{m/s }\boldsymbol{E}\right) = \left(168\text{ lb}\right)\boldsymbol{v}_{man,f} + \left(95.0\text{ lb}\cdot\text{m/s }\boldsymbol{E}\right)$$
$$\boldsymbol{v}_{man,f} = 1.91\,\text{m/s }\boldsymbol{E}$$

11. **Correct answer: A**

Since no work is done on the system, the energy of the system is conserved.

And since no net external impulse acts upon the system, momentum is also conserved.



initial momentum = final momentum

$$\left(2\text{M} + \text{M}\right)\left(0\text{ m/s}\right) = \left(2M\right)v_2 + \left(M\right)v_1$$
$$v_1 = -\frac{2M}{M}v_2 = -2v_2$$

initial energy = final energy

$$\frac{1}{2}kx^2 = \frac{1}{2}\left(2M\right)\left(v_2\right)^2 + \frac{1}{2}\left(M\right)\left(v_1\right)^2$$
$$kx^2 = \left(2M\right)\left(v_2\right)^2 + \left(M\right)\left(-2v_2\right)^2 = 6Mv_2^2$$
$$v_2 = \sqrt{\frac{kx^2}{6M}}$$

12. **Correct answer: A**

$$\omega(t) = 3.00 + 0.400t + 29.0t^2$$
$$\omega(0) = 3.00$$
$$\alpha_{avg}(t) = \frac{\omega(t) - \omega(0)}{t - 0} = \frac{0.400t + 29.0t^2}{t} = 0.400 + 29.0t$$
$$\alpha_{avg}(5.000 \text{ ms}) = 0.400 + 29.0\left(5.000 \times 10^{-3}\right) = 0.545\left(\text{rad/s}^2\right)$$

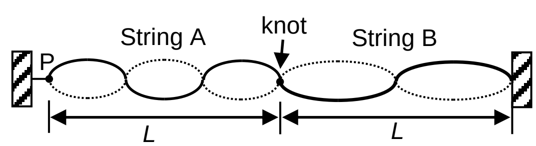
13. **Correct answer: D**

$$P_{total} = 1.00 \text{ atm} + \rho g h$$
$$= 1.01 \times 10^5 \frac{\text{N}}{\text{m}^2} + \left(1.00 \times 10^3 \frac{\text{kg}}{\text{m}^3}\right)\left(9.80 \text{ m/s}^2\right)\left(6.00 \text{ m}\right)$$
$$= 1.60 \times 10^5 \frac{\text{N}}{\text{m}^2}\left(\frac{1\text{atm}}{1.01 \times 10^5 \frac{\text{N}}{\text{m}^2}}\right) = 1.58 \text{ atm}$$

14. **Correct answer: D**

Putting a 185 kg boat above the point in question would not change the pressure 6.00 m below the surface of the lake since the boat displaces an equivalent mass (and weight) of water.
185 kg – 185 kg = 0

15. **Correct answer: B**

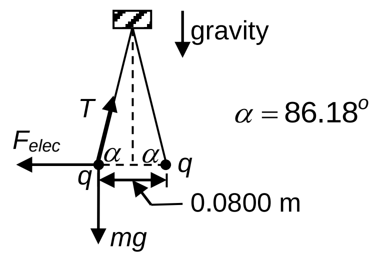


$$\frac{3}{2}\lambda_A = L \quad \to \quad \lambda_A = \left(\frac{2}{3}\right)L \quad \text{and} \quad \lambda_B = L$$
$$v_B = f\lambda_B = fL = \sqrt{\frac{T}{\mu_B}}$$
$$v_A = f\lambda_A = f\left(\frac{2}{3}\right)L = \sqrt{\frac{T}{\mu_A}}$$
$$\frac{v_B}{v_A} = \frac{fL}{\left(\frac{2}{3}\right)fL} = \frac{\sqrt{\frac{T}{\mu_B}}}{\sqrt{\frac{T}{\mu_A}}}$$
$$\frac{v_B}{v_A} = \frac{3}{2} = \sqrt{\frac{\mu_A}{\mu_B}} \quad \to \quad \frac{\mu_A}{\mu_B} = \frac{9}{4} = 2.25$$

16. **Correct answer: C**

$$Q_{total} = Q_{\text{ice(-10)}\to\text{ice(0)}} + Q_{\text{ice(0)}\to\text{water(0)}} + Q_{\text{water(0)}\to water\text{(10)}}$$
$$= m_{ice}c_{ice}\left(0 - -10\ ^{o}\text{C}\right) + m_{ice}L + m_{water}c_{water}\left(10\ ^{o}\text{C} - 0\right)$$
$$= (0.1\text{kg})\left(2093\frac{\text{J}}{\text{kgC}^{o}}\right)\left(10\ ^{o}\text{C}\right) + (0.1\text{kg})\left(334\times10^{3}\frac{\text{J}}{\text{kg}}\right) + (0.1\text{kg})\left(4186\frac{\text{J}}{\text{kgC}^{o}}\right)\left(20\ ^{o}\text{C}\right)$$
$$= 43865\,\text{J} = P_{electrical}t = \frac{V^2}{R}t = \frac{(24.0\,\text{V})^2}{6.00\,\Omega}t$$
$$t = 457\,\text{s}$$

17. **Correct answer: E**



$$T\sin(\alpha) = mg$$
$$T\cos(\alpha) = k\frac{q^2}{R^2}$$
$$\tan(\alpha) = \frac{mgR^2}{kq^2}$$
$$q^2 = \frac{mgR^2}{k\tan(\alpha)} = \frac{(0.0250)(9.80)(0.0800)^2}{(8.988\times10^{9})\tan(86.18^{o})}\text{C}^2 = 1.165\times10^{-14}\text{C}^2$$
$$q = 1.08\times10^{-7}\text{C} = 108\text{ nC}$$

18. **Correct answer: B**

$$KE = mc^2 - m_oc^2$$
$$3m_oc^2 = mc^2 - m_oc^2$$
$$4m_oc^2 = mc^2$$
$$4m_oc^2 = \frac{m_oc^2}{\sqrt{1-\frac{v^2}{c^2}}}$$
$$\sqrt{1-\frac{v^2}{c^2}} = \frac{1}{4}$$
$$1-\frac{v^2}{c^2} = \frac{1}{16}$$
$$\frac{v}{c} = \sqrt{\frac{15}{16}} = 0.968$$

19. **Correct answer: D**
Newton's First Law states that a body not acted on by any forces moves with constant velocity.

20. **Correct answer: B**

$$|v| = \left|\frac{x_2 - x_1}{t_2 - t_1}\right| = \left|\frac{(6.0\text{ m}) - (0.0\text{ m})}{(5.0\text{ s}) - (0.0\text{ s})}\right| = 1.2\text{ m/s}$$

21. **Correct answer: B**

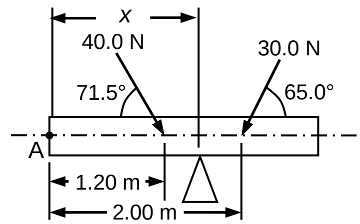
$$x_2 - x_1 = v_1 t + \tfrac{1}{2}a(t_2 - t_1)^2 \quad \Rightarrow \quad a = 2\frac{(x_2 - x_1) - v_1 t}{(t_2 - t_1)^2} = 2\frac{(6.0\text{ m}) - (0.0\text{ m}) - 0}{[(5.0\text{ s}) - (0.0\text{ s})]^2} = 0.48\text{ m/s}^2$$

22. **Correct answer: D**

$$\tau = r_1 F_1 \sin\theta_1 + r_2 F_2 \sin\theta_2 = (1.20\text{ m})(40.0\text{ N})\sin 71.5^\circ + (2.00\text{ m})(30.0\text{ N})\sin 65.0^\circ = 99.9\text{ N}\cdot\text{m}$$

23. **Correct answer: D**

Using the convention that positive torque is counterclockwise and negative torque is clockwise:



$$0 = r_1 F_1 \sin\theta_1 - r_2 F_2 \sin\theta_2$$
$$= (x - 1.20\text{ m})(40.0\text{ N})\sin 71.5^\circ - (2.00\text{ m} - x)(30.0\text{ N})\sin 65.0^\circ$$
$$\Rightarrow \quad x = \frac{(1.20\text{ m})(40.0\text{ N})\sin 71.5^\circ + (2.00\text{ m})(30.0\text{ N})\sin 65.0^\circ}{(40.0\text{ N})\sin 71.5^\circ + (30.0\text{ N})\sin 65.0^\circ} = 1.53\text{ m}$$

24. **Correct answer: E**

If no external forces act on a system, the total momentum of the system is always conserved.

25. **Correct answer: D**

The diameter of a table tennis ball is 4.0 cm.

$$V = \tfrac{4}{3}\pi r^3 = 4\left(2.0\times 10^{-2}\text{ m}\right)^3 = 3.2\times 10^{-5}\text{m}^3 \approx 3\times 10^{-5}\text{m}^3$$

26. **Correct answer: E**

$$\Delta K + \Delta U_{gravity} + \Delta U_{spring} = 0 \quad \Rightarrow \quad \tfrac{1}{2}mv_2^2 - \tfrac{1}{2}mv_1^2 + mg\,(h_2 - h_1) + \tfrac{1}{2}kx_2^2 - \tfrac{1}{2}kx_1^2 = 0 \quad \Rightarrow$$

$$k = \frac{mv_2^2 - mv_1^2 + 2mg\,(h_2 - h_1)}{x_1^2 - x_2^2} = \frac{0 - 0 + 2(3.00\text{ kg})\left(9.80\text{ m/s}^2\right)(-6.00\text{ cm})}{(2.00\text{ cm})^2 - (4.00\text{ cm})^2} = 29.4\text{ N/cm}$$

27. **Correct answer: B**

$$\Delta K_{tranlational} + \Delta K_{rotational} + \Delta U = 0 \quad \Rightarrow$$
$$\tfrac{1}{2}mv_2^2 - \tfrac{1}{2}mv_1^2 + \tfrac{1}{2}mr_{gyration}^2\omega_2^2 - \tfrac{1}{2}mr_{gyration}^2\omega_1^2 + mg\,(h_2 - h_1) = 0$$

Rolling without slipping implies $\omega = \dfrac{v}{R}$:

$$v = \sqrt{-\frac{2g(h_2 - h_1)}{1 + \frac{r_{gyrate}^2}{R^2}}} = \sqrt{-\frac{2\left(9.80\text{ m/s}^2\right)(-1.50\text{ m})\sin 30.0^\circ}{1 + \frac{(12.0\text{ cm})^2}{(15.0\text{ cm})^2}}} = 2.99\text{ m/s}$$

28. **Correct answer: C**

Using a coordinate system with the x direction toward the east and the y direction toward the north:

$A_x = 4.00\text{ m}$, $A_y = 0.00\text{ m}$, $B_x = 3.00\text{ m}$, $B_y = 4.00\text{ m}$.

$$R_x = A_x + B_x = 4.00\text{ m} + 0.00\text{ m} = 4.00\text{ m},\ R_y = A_y + B_y = 0.00\text{ m} + 3.00\text{ m} = 3.00\text{ m}$$

$$R = \sqrt{R_x^2 + R_y^2} = \sqrt{(4.00\text{ m})^2 + (3.00\text{ m})^2} = 5.00\text{ m},\ \theta_R = \arctan\frac{R_y}{R_x} = \arctan\frac{3.00\text{ m}}{4.00\text{ m}} = 36.9°\text{ N of E}$$

29. **Correct answer: A**
As both blocks remain in contact, Newton's Second Law can be solved for the combined system:

$$F = m_{total}a \quad \Rightarrow \quad a = \frac{F}{m_{total}}$$

Solving Newton's Second Law for the 3.00 kg block alone for the unknown contact force:

$$F_{contact} = m_{3.00\text{kg}}a = m_{3.00\text{kg}}\frac{F}{m_{total}} = (3.00\text{ kg})\frac{F}{(3.00\text{ kg} + 4.00\text{ kg})} = \tfrac{3}{7}F$$

30. **Correct answer: C**

$$P = \frac{W}{t} \quad \Rightarrow \quad t = \frac{W}{P} = \frac{mg\Delta h}{P} = \frac{(50.0\text{ kg})(9.80\text{ m/s}^2)(4.00\text{ m})}{(200.\text{ W})} = 9.80\text{ s}$$

31. **Correct answer: B**
The stable orientation for floating is when the center of mass of the floating object is as low as possible. It is easy to verify that when 0.400 cm of this block is below the water, the center of mass is lowest when the shortest dimension is vertically oriented. An object floats when the weight of the displaced fluid is equal to the weight of the object:

$$\rho_{object}gV_{object} = \rho_{fluid}gV_{displaced} \quad \Rightarrow$$

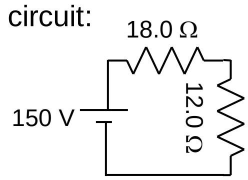
$$\rho_{object} = \frac{\rho_{fluid}V_{displaced}}{V_{object}} = \frac{(1.50\text{ kg/m}^3)(0.400\text{ cm})(2.00\text{ cm})(3.00\text{ cm})}{(1.00\text{ cm})(2.00\text{ cm})(3.00\text{ cm})} = 0.600\text{ kg/m}^3$$

32. **Correct answer: A**
The electric field is $E = -\frac{\Delta V}{\Delta s}$. The ΔV is the same between each pair of curves so the electric field magnitude will be the greatest where the curves are closest together (smallest Δs).

33. **Correct answer: B**
The equivalent resistance of the 20.0 Ω and the 30.0 Ω resistors in parallel is

$$R_{eq1} = \left(\frac{1}{20.0\ \Omega} + \frac{1}{30.0\ \Omega}\right)^{-1} = 12.0\ \Omega.$$

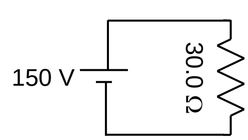
Resulting in the equivalent circuit:



The equivalent resistance of the 18.0 Ω and the 12.0 Ω resistors in series is

$$R_{eq2} = 18.0\ \Omega + 12.0\ \Omega = 30.0\ \Omega$$

Resulting in the equivalent circuit:



Using Ohm's Law, the current that flows in this circuit is

$$I = \frac{V}{R} = \frac{150.\,V}{30.0\ \Omega} = 5.00\ \text{A}$$

This current is the current that flows from the voltage source which is in the same branch as the 18.0 Ω resistor of the original circuit.

34. **Correct answer: B**

$$m = -\frac{d_i}{d_o} \quad \Rightarrow \quad d_i = -md_o \quad \text{and} \quad \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} \quad \Rightarrow$$

$$f = \frac{d_o d_i}{d_o + d_i} = \frac{-md_o}{(1-m)} = \frac{-(4.00)(20.0\ \text{cm})}{(1-4.00)} = 26.7\ \text{cm}$$

35. **Correct answer: A**

One may reach the answer by knowing $F = qvB\sin\theta \quad \Rightarrow \quad B = \dfrac{F}{qv\sin\theta}$.

Substituting units for each quantity on the right: $[\text{units of } B] = \dfrac{\text{N}}{\text{C}\cdot\text{m/s}} = \dfrac{\text{N}\cdot\text{s}}{\text{C}\cdot\text{m}}$