1. A 45 kg boy stands on 30 kg platform suspended by a rope passing over a stationary pulley that is free to rotate. The other end of the rope is held by the boy. The masses of the rope and pulley are negligible. Ignore the friction in the pulley.

   a. If the rope and the boy are at rest, what is the tension in the rope?

   The boy now pulls on the rope so that the acceleration of the boy and the platform is 1.5 m/s$^2$ upward.

   b. What is the tension force in the rope under these new conditions?

   c. Under these conditions, what is the force exerted by the platform on the boy?

After a short time, the boy and the platform reach and sustain an upward velocity of 0.3 m/s.

   d. Determine the power output of the boy required to sustain this velocity.
2. A block of mass $m$, acted on by a force $F$ directed horizontally, slides up an inclined plane that makes an angle $\theta$ with the horizontal. The coefficient of sliding friction between the block and the plane is $\mu$.

a. On the diagram of the block below, draw and label all the forces that act on the block as it slides up the plane.

![Diagram of block on inclined plane]

b. Develop an expression in terms of $m$, $\theta$, $\mu$, $F$, and $g$ for the block's acceleration up the incline.

c. Develop an expression for the magnitude of the force $F$ that will allow the block to slide up the plane with a constant velocity. What relation must $\theta$ and $\mu$ satisfy in order for the solution to be physically meaningful?
3. A horizontal force $F$ is applied to a small block of mass $m_1$ to make it slide along the top of a larger block of mass $m_2$ and length $L$. The coefficient of kinetic friction between the blocks is $\mu$. The larger block slides without friction along a horizontal surface. The blocks start from rest with the smaller block at one end of the larger block.
   
   a. On the diagram below draw and label all the forces acting on each block.

   b. Find the acceleration of each block: $a_1$ and $a_2$, relative to the horizontal surface.
   
   c. In terms of $L$, $a_1$, and $a_2$ find the time $t$ needed for the small block to slide off the end of the larger block.
   
   d. Find the expression for the energy dissipated as heat because of the friction between the blocks.
4. A 500 kg box rests on a platform of the electrical fork-lift. Starting from rest at time $t = 0$, the box is lowered with a downward acceleration of $1.4 \text{ m/s}^2$.

   a. Determine the upward force exerted by the horizontal platform on the box as it is lowered.

      At time $t = 0$, the fork-lift also begins to move forward with an acceleration of $1.9 \text{ m/s}^2$ while lowering the box. The box doesn't slip or tip over.

   b. Determine the friction force on the box.

   c. If the box doesn't slip, determine the minimum coefficient of static friction between the box and the platform.

   d. Determine the expression that describes the path of the box ($y$ as a function of $x$), assuming, at time $t = 0$ the box has a horizontal position $x_0 = 0$ and a vertical position $y = 2.5 \text{ m}$ above the ground, with zero velocity.

   e. On the coordinate system below sketch the path taken by the box.
5. A curved road with a radius of 150 m is banked at an angle of 25°. The coefficient of static friction between the tires and the surface is 0.4.

a. Find the speed of a car that doesn’t require any friction force to prevent skidding.

b. Find the maximum speed that the car can reach before sliding up the banking. On the diagram below show and label all the forces acting on the car at this speed.

c. Find the minimum speed that the car can reach before sliding down the banking. On the diagram below show and label all the forces acting on the car at this speed.
6. A sphere of mass $m$ is released from rest. As it falls, the air exerts a resistance force on the sphere that is proportional to the sphere’s velocity $F_r = -kV$. Neglect the buoyant force of the air.

   a. On the diagram below show and label all forces acting on the sphere just after it is released.

   b. On the diagram below show and label all forces acting on the sphere after it was falling for a long time and the terminal velocity is reached.

   c. Determine the terminal velocity of the sphere.

   d. Draw three graphs for the sphere motion just after the sphere is released as well as after a long time.
7. A block of mass \( m \) has an initial velocity \( V_0 \) at time \( t = 0 \), slides on a horizontal surface. The sliding friction force exerted on the block by the surface is directly proportional to its velocity \( F_r = -kV \).
   
a. Determine the amount of work that must be done on the block to bring it to rest.
   b. Determine the expression for the acceleration of the block in terms of \( m \), \( k \), and \( V_0 \).
   c. Determine the speed of the block as a function of time.
   d. Determine the total distance the block slides.

8. A car of mass \( m \), initially at rest at time \( t = 0 \), is driven to the right along a straight line on a horizontal road. The engine applies a constant force \( F_o \). While moving the car encounters a resistance force \( F_r = -kv \), where \( v \) is the velocity of the car and \( k \) is a positive constant.
   
a. On the diagram below show and label all force acting on the car as it moves to the right.
   
b. Determine the horizontal acceleration of the car.
   c. Derive an expression for the car’s velocity as a function of time in terms of \( k \) and \( F_o \).
9. A block of mass $m$ moving along the $x$–axis with a velocity $v$ is slowed by the resistance force $F_r = -kV$, where $k$ is a constant. At time $t = 0$, the block has a velocity $V_0$ at position $x= 0$.

a. What is the initial acceleration of the block?

b. Derive an expression for the block’s velocity as a function of time $t$, and sketch this function on the axes below.

c. Derive an expression for the distance of the block as a function of time and sketch this function on the axes below.
d. Determine the traveled distance by the block form \( t = 0 \) to \( t = \infty \).

10. A block with a mass \( m \) slides down an inclined plane which makes an angle \( \theta \) with the horizontal. The block starts from rest at time \( t = 0 \) and is subject to a velocity-dependent resistance force \( F_r = -bV \), where \( V \) is the velocity of the block and \( b \) is a positive constant.

a. On the diagram below show and label all the applied force on the block.

b. Write but do not solve a differential equation that can be used to find the block’s velocity.

c. Find the terminal velocity of the block.

d. Solve the differential equation for the block’s velocity and present it in terms of \( m, b, g, \theta \).
11. A block of mass $m$ is pulled along a rough horizontal surface by a force $F$ that is applied at an angle $\theta$ above the horizontal. The block moves at a constant horizontal acceleration $a$. Express all the results in terms of $m$, $\theta$, $F$, $a$, and fundamental constants.

a. Below show and label a free-body diagram with all forces acting on the block.

b. Write an expression for the normal force applied by the surface on the block.

c. Determine the coefficient of kinetic friction between the block and the surface.

d. Sketch two graphs: velocity and displacement as functions of time, if the block started from rest at $x = 0$ and $t = 0$.

e. The applied force can be large enough to levitate the block above the surface. Derive an expression for the maximum acceleration that the block still maintains a contact with the surface.
12. A small block of mass $m_1 = 0.4$ kg is placed on a long slab of mass $m_2 = 2.8$ kg. Initially, the slab is stationary and the block moves at a speed of $v_o = 3$ m/s. The coefficient of kinetic friction between the block and the slab is 0.15 and there is no friction between the slab and the surface on which it moves.

a. On the diagram below show and label all forces applied on both the block and slab.

\[ \text{Block} \quad m_1 \quad \text{Slab} \quad m_2 \]

At some moment later, before the block reaches the end of the slab they both attain identical speeds $v_1$.

b. Determine the speed $v_1$.

c. Determine the distance traveled by the slab before it reaches the speed $v_1$.

d. Find the work done by the friction force on the slab from the beginning to the time when it reaches $v_1$. 
13. Two blocks with masses \( m_B \) and \( m_C \) are connected with a light string and placed on the surface on an inclined plane. Block A with a mass \( m_A \) is suspended from a string that goes over a pulley and is connected to block B. The two blocks on the inclined plane move up the incline with a constant speed. The friction force between block B and the surface is \( f_B \) and the friction force between block C and surface is \( f_C \).

a. On the diagram below show and label all forces applied on each block if \( m_A \) was moving down.

b. Find the mass of block A that the system can move with a constant speed.

c. The string between block B and C is cut, find the acceleration of block C.
14. Block B, with a mass $M_B$, rests on the top of block A, with a mass $M_A$, which is placed on a horizontal tabletop. A light string attached to block A passes over a pulley and is connected to block C which is suspended from the pulley. The coefficient of kinetic friction between all the surfaces is $\mu_k$ and coefficient of static friction is $\mu_s$.

   a. Find the mass $M_C$ of block C that can prevent the two blocks from sliding on the tabletop.

   b. Find the mass $M_C$ that block C can have so the blocks will move at a constant speed when the system is released.

   c. Find the minimum value of mass $M_C$ that will be enough to make block B to slide off block A.
Free-Response Answers:

1. A. 367.5 N  
   B. 423.75 N  
   C. 84.75 N  
   D. 220.5 W

2. A.  
   \[ F_N \]  
   \[ m \]  
   \[ m \] 

   B. \( a = \frac{F(\cos \theta - u \sin \theta) - mg(u \cos \theta + \sin \theta)}{m} \)  

   C. \( F = \frac{mg(u \cos \theta + \sin \theta)}{\cos \theta - u \sin \theta}, \mu < 1/\tan \theta \)

3. A.  
   \[ F_{N1} \]  
   \[ F_{FR} \]  
   \[ m_{1g} \]  

   B. \( a_1 = \frac{F - \mu m_{1g}}{m_1}, a_2 = \frac{\mu m_{1g}}{m_2} \)  

   C. \( t = \sqrt{\frac{2L}{a_1 - a_2}} \)  

   D. \( W = \mu m_{1g}gL \)
4. A. 4200N  
   B. 950N  
   C. 0.23  
   D. 2.5 – 0.74x  

5. A. 26.2 m/s  
   B.  
   
   \[ v = \sqrt{\frac{Rg(\sin \theta + \mu \cos \theta)}{\cos \theta - \mu \sin \theta}} \]  
   V=39.6 m/s
6. A. 

B. 

C.  \( \frac{mg}{k} \) 

D. 

\[ V = 9.1 \text{m/s} \] 

\[ v = \sqrt{\frac{Rg(\sin \theta - \mu \cos \theta)}{\cos \theta + \mu \sin \theta}} \]
7. A. \[ \frac{1}{2} m v_o^2 \]

B. \[ a = \frac{-kv}{m} \]

C. \[ v = v_o \cdot e^{-kt} \]

D. \[ x = \frac{v_0 m}{k} \]

8. A. \[ \text{Diagram of forces} \]

B. \[ a = \frac{F_o - kv}{m} \]

C. \[ v = \frac{F_o}{k} (1 - e^{-\frac{kt}{m}}) \]

9. A. \[ a = \frac{-kv}{m} \]

B. \[ v = v_o \cdot e^{-\frac{kt}{m}} \]
C. \[ x = \frac{v_0 m}{k} (1 - e^{-\frac{k}{m} t}) \]

D. \[ x = \frac{mv_0}{k} \]

10. A. 

B. \[ \frac{mg \sin \theta - bV}{m} = \frac{dv}{dt} \]

C. \[ v_t = \frac{mg \sin \theta}{b} \]

D. \[ v = \frac{mg \sin \theta}{b} (1 - e^{-\frac{b}{m} t}) \]

11. A. 

B. \[ -F \sin \theta + mg = F_N \]

C. \[ \frac{F \cos \theta - ma}{-F \sin \theta + mg} = \mu_k \]
12. A. 

B. 0.375 m/s 

C. 0.33 m 

D. 0.19 J 

13. A. 

B. \( m_A = \frac{(m_C + m_B) g \sin \theta + f_C + f_B}{g} \) 

C. \( a = \frac{m_C g \sin \theta - f_C}{m_C} \)
14. A. \( M_c = \mu_s (M_A + M_B) \)

B. \( M_c = (M_A + M_B)\mu_k \)

C. \( \frac{2\mu(m_a+m_b)}{1-\mu} < m_c \)