Review

trough problem solving

A basketball star covers 2.80 m horizontally in a jump to dunk the ball. His motion through space can be modeled precisely as that of a particle at his center of mass. His center of mass is at elevation 1.02 m when he leaves the floor. It reaches a maximum height of 1.85 m above the floor, and is at elevation 0.900 m when he touches down again. Determine (a) his time of flight (his "hang time"), (b) his horizontal and (c) vertical velocity components at the instant of takeoff, and (d) his takeoff angle. (e) For comparison, determine the hang time of a whitetail deer making a jump with center-of-mass elevations

$y_i =$ 1.20 m, $y_{max} =$ 2.50 m, $y_f =$ 0.700 m.

From the instant he leaves the floor until just before he lands, the basketball star is a projectile. His vertical velocity and vertical displacement are related by the equation $v_{yf}^2 = v_{yi}^2 + 2a_y(y_f - y_i)$.

For the downward part of the flight, the equation gives $v_{yf}^2 = 0 + 2(-9.80\ \text{m/s}^2)(0.900 - 1.85)\ \text{m}$. Thus the vertical velocity just before he lands is

$$v_{yf} = -4.32\ \text{m/s}.$$

(a) His hang time may then be found from $v_{yf} = v_{yi} + a_y t$:

$$-4.32\ \text{m/s} = 4.03\ \text{m/s} + (-9.80\ \text{m/s}^2)t$$

$$t = \boxed{0.852\ \text{s}}.$$

A basketball star covers 2.80 m horizontally in a jump to dunk the ball. His motion through space can be modeled precisely as that of a particle at his center of mass. His center of mass is at elevation 1.02 m when he leaves the floor. It reaches a maximum height of 1.85 m above the floor, and is at elevation 0.900 m when he touches down again. Determine (a) his time of flight (his "hang time"), (b) his horizontal and (c) vertical velocity components at the instant of takeoff, and (d) his takeoff angle. (e) For comparison, determine the hang time of a whitetail deer making a jump with center-of-mass elevations
y_i = 1.20 m, y_{max} = 2.50 m, y_f = 0.700 m.

(b) Looking at the total horizontal displacement during the leap, $x = v_{xi}t$ becomes

$$2.80\text{ m} = v_{xi}(0.852\text{ s})$$

which yields $v_{xi} = \boxed{3.29\text{ m/s}}$.

c) $v_{yi} = \boxed{4.03\text{ m/s}}$. See above for proof.

(d) The takeoff angle is: $\theta = \tan^{-1}\left(\frac{v_{yi}}{v_{xi}}\right) = \tan^{-1}\left(\frac{4.03\text{ m/s}}{3.29\text{ m/s}}\right) = \boxed{50.8°}$.

A basketball star covers 2.80 m horizontally in a jump to dunk the ball. His motion through space can be modeled precisely as that of a particle at his center of mass. His center of mass is at elevation 1.02 m when he leaves the floor. It reaches a maximum height of 1.85 m above the floor, and is at elevation 0.900 m when he touches down again. Determine (a) his time of flight (his "hang time"), (b) his horizontal and (c) vertical velocity components at the instant of takeoff, and (d) his takeoff angle. (e) For comparison, determine the hang time of a whitetail deer making a jump with center-of-mass elevations

y_i = 1.20 m, y_{max} = 2.50 m, y_f = 0.700 m.

e) Similarly for the deer, the upward part of the flight gives $v_{yf}^2 = v_{yi}^2 + 2a_y(y_f - y_i)$:

$$0 = v_{yi}^2 + 2(-9.80 \text{ m/s}^2)(2.50 - 1.20) \text{ m}$$

so $v_{yi} = 5.04 \text{ m/s}$.

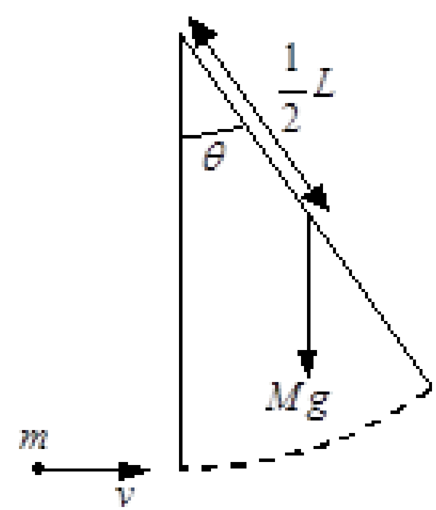
For the downward part, $v_{yf}^2 = v_{yi}^2 + 2a_y(y_f - y_i)$ yields $v_{yf}^2 = 0 + 2(-9.80 \text{ m/s}^2)(0.700 - 2.50) \text{ m}$ and $v_{yf} = -5.94 \text{ m/s}$.

The hang time is then found as $v_{yf} = v_{yi} + a_y t$:

$-5.94 \text{ m/s} = 5.04 \text{ m/s} + (-9.80 \text{ m/s}^2)t$ and

$$\boxed{t = 1.12 \text{ s}}.$$

A thin uniform rectangular sign hangs vertically above the door of a shop. The sign is hinged to a stationary horizontal rod along its top edge. The mass of the sign is 2.40 kg and its vertical dimension is 50.0 cm. The sign is swinging without friction, becoming a tempting target for children armed with snowballs. The maximum angular displacement of the sign is 25.0° on both sides of the vertical. At a moment when the sign is vertical and moving to the left, a snowball of mass 400 g, traveling horizontally with a velocity of 160 cm/s to the right, strikes perpendicularly the lower edge of the sign and sticks there. (a) Calculate the angular speed of the sign immediately before the impact. (b) Calculate its angular speed immediately after the impact. (c) The spattered sign will swing up through what maximum angle?



(a) Calculate the angular speed of the sign immediately before the impact.

(a) Let ω be the angular speed of the signboard when it is vertical.

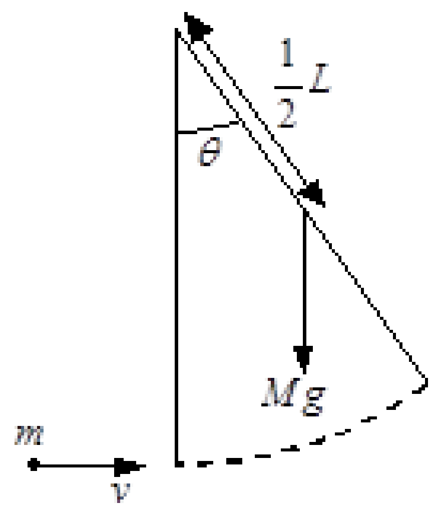
$$\frac{1}{2}I\omega^2 = Mgh$$

$$\therefore \frac{1}{2}\left(\frac{1}{3}ML^2\right)\omega^2 = Mg\frac{1}{2}L(1-\cos\theta)$$

$$\therefore \omega = \sqrt{\frac{3g(1-\cos\theta)}{L}}$$

$$= \sqrt{\frac{3(9.80\ \text{m/s}^2)(1-\cos 25.0°)}{0.50\ \text{m}}}$$

$$= \boxed{2.35\ \text{rad/s}}$$



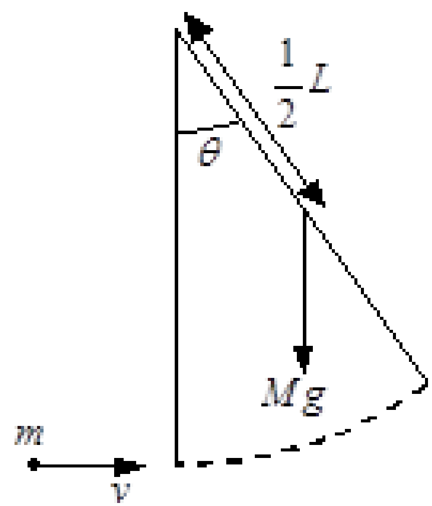
Calculate its angular speed immediately after the impact.

(b) $I_f \omega_f = I_i \omega_i - m vL$ represents angular momentum conservation

$$\therefore \left(\frac{1}{3} M L^2 + m L^2\right) \omega_f = \frac{1}{3} M L^2 \omega_i - m vL$$

$$\therefore \omega_f = \frac{\frac{1}{3} M L\omega_i - m v}{\left(\frac{1}{3} M + m\right) L}$$

$$= \frac{\frac{1}{3}(2.40 \text{ kg})(0.5 \text{ m})(2.347 \text{ rad/s}) - (0.4 \text{ kg})(1.6 \text{ m/s})}{\left[\frac{1}{3}(2.40 \text{ kg}) + 0.4 \text{ kg}\right](0.5 \text{ m})} = \boxed{0.498 \text{ rad/s}}$$



The spattered sign will swing up through what maximum angle?

(c) Let h_{CM} = distance of center of mass from the axis of rotation.

$$h_{CM} = \frac{(2.40\text{ kg})(0.25\text{ m}) + (0.4\text{ kg})(0.50\text{ m})}{2.40\text{ kg} + 0.4\text{ kg}} = 0.2857\text{ m} .$$

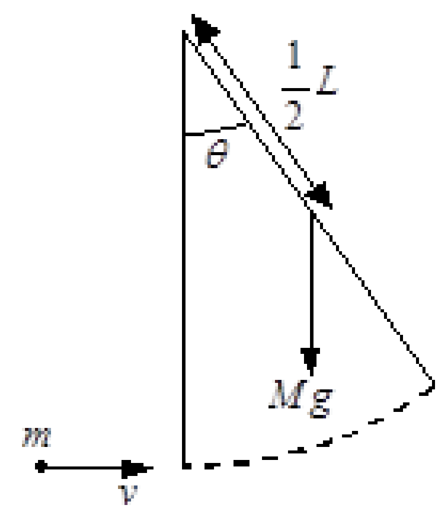
Apply conservation of mechanical energy:

$$(M+m)\,g h_{CM}\,(1-\cos\theta) = \frac{1}{2}\left(\frac{1}{3}ML^2 + mL^2\right)\omega^2$$

$$\therefore \theta = \cos^{-1}\left[1 - \frac{\left(\frac{1}{3}M + m\right)L^2\omega^2}{2(M+m)\,g h_{CM}}\right]$$

$$= \cos^{-1}\left\{1 - \frac{\left[\frac{1}{3}(2.40\text{ kg}) + 0.4\text{ kg}\right](0.50\text{ m})^2(0.498\text{ rad/s})^2}{2(2.40\text{ kg} + 0.4\text{ kg})(9.80\text{ m/s}^2)(0.2857\text{ m})}\right\}$$

$$= \boxed{5.58^\circ}$$



X.42. A Chevrolet Corvette convertible can brake to a stop from a speed of 60.0 mi/h in a distance of 123 ft on a level roadway. What is its stopping distance on a roadway sloping downward at an angle of 10.0°?

Problem-Solving Hints Newton's Laws

- Conceptualize the problem – draw a diagram
- Categorize the problem
  - Equilibrium ($\Sigma\mathbf{F} = 0$) or Newton's Second Law ($\Sigma\mathbf{F} = m\,\mathbf{a}$)
- Analyze
  - Draw free-body diagrams for each object
  - Include only forces acting on the object

Problem-Solving Hints Newton's Laws, cont

- Analyze, cont.
  - Establish coordinate system
  - Be sure units are consistent
  - Apply the appropriate equation(s) in component form
  - Solve for the unknown(s)
- Finalize
  - Check your results for consistency with your free-body diagram
  - Check extreme values

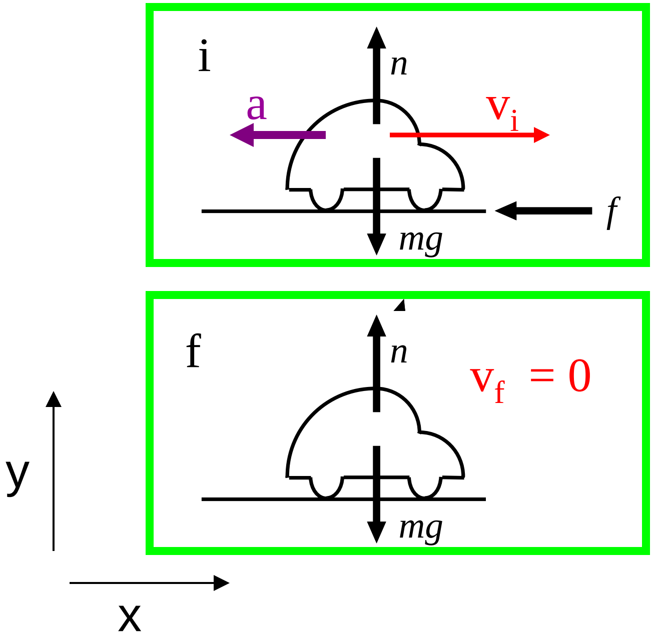
Forces of Friction

- When an object is in motion on a surface or through a viscous medium, there will be a resistance to the motion
  - This is due to the interactions between the object and its environment
- This resistance is called the *force of friction*

Forces of Friction, cont.

- Friction is proportional to the normal force
  - $f_s \leq \mu_s n$ and $f_k = \mu_k n$
  - These equations relate the magnitudes of the forces, they are not vector equations
- The force of static friction is generally greater than the force of kinetic friction
- The coefficient of friction (μ) depends on the surfaces in contact

42. A Chevrolet Corvette convertible can brake to a stop from a **speed** of 60.0 mi/h in a **distance** of 123 ft on a level roadway. What is its stopping distance on a roadway sloping downward at an angle of 10.0°?



$$\sum F_y = 0: \qquad +n - mg = 0$$

$$f = \mu_s n = \mu_s mg$$

$$\sum F_x = ma_x :$$

Kinematic Equations -- summary

Table 2.2

Kinematic Equations for Motion of a Particle Under Constant Acceleration

Equation	Information Given by Equation
$v_{xf} = v_{xi} + a_x t$	Velocity as a function of time
$x_f = x_i + \frac{1}{2}(v_{xi} + v_{xf})t$	Position as a function of velocity and time
$x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2$	Position as a function of time
$v_{xf}^2 = v_{xi}^2 + 2a_x(x_f - x_i)$	Velocity as a function of position

Note: Motion is along the x axis.

Kinematic Equations, specific

- For constant *a*,

$$v_{xf}^2 = v_{xi}^2 + 2a_x\left(x_f - x_i\right)$$

- Gives final velocity in terms of acceleration and displacement
- Does not give any information about the time

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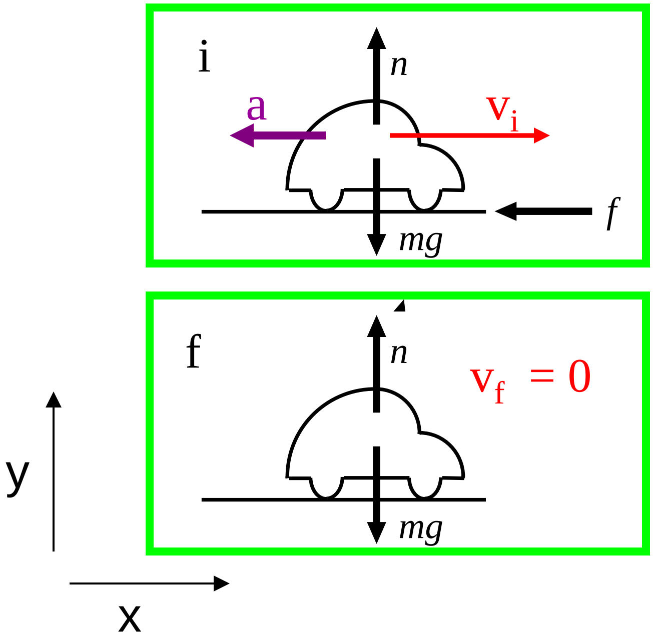


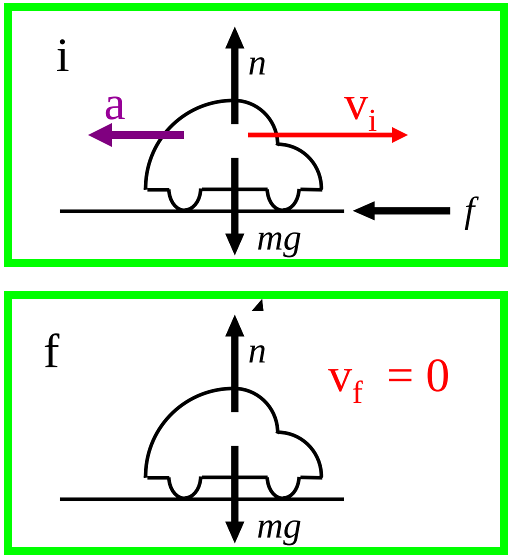
First we find the coefficient of friction:

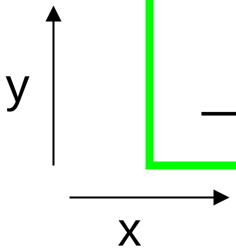
$$\sum F_y = 0: \qquad +n - mg = 0$$

$$f = \mu_s n = \mu_s mg$$

$$\sum F_x = ma_x: \qquad v_f^2 = v_i^2 + 2a_x \Delta x = 0$$

42. A Chevrolet Corvette convertible can brake to a stop from a speed of 60.0 mi/h in a distance of 123 ft on a level roadway. What is its stopping distance on a roadway sloping downward at an angle of 10.0°?





First we find the coefficient of friction:

$$\sum F_y = 0: \qquad +n - mg = 0$$

$$f = \mu_s n = \mu_s mg$$

$$\sum F_x = ma_x: \qquad v_f^2 = v_i^2 + 2a_x \Delta x = 0$$

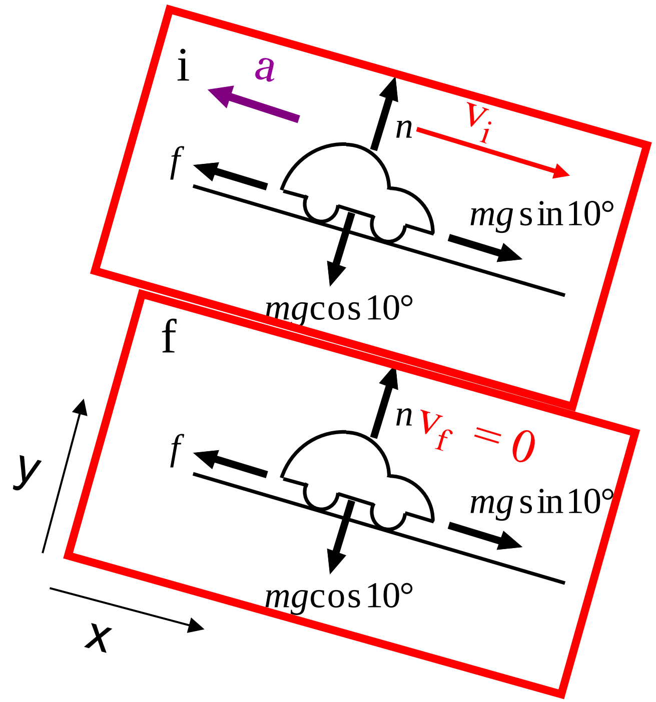
1 mile = 1.61 km
1 foot= 0.305 m

$$-\mu_s mg = -\frac{mv_i^2}{2\Delta x}$$

$$\mu_s = \frac{v_i^2}{2g\Delta x} = \frac{(88 \text{ ft/s})^2}{2(32.1 \text{ ft/s}^2)(123 \text{ ft})} = 0.981$$

42. A Chevrolet Corvette convertible can brake to a stop from a speed of 60.0 mi/h in a distance of 123 ft on a level roadway. What is its stopping distance on a roadway sloping downward at an angle of 10.0°?

Now on the slope



$$\sum F_y = 0: \quad +n - mg\cos 10° = 0$$

$$f_s = \mu_s n = \mu_s mg\cos 10°$$

$$\sum F_x = ma_x: \quad -\mu_s mg\cos 10° + mg\sin 10° = -\frac{mv_i^2}{2\Delta x}$$

$$\Delta x = \frac{v_i^2}{2g(\mu_s\cos 10° - \sin 10°)}$$

$$= \frac{(88\ \text{ft/s})^2}{2(32.1\ \text{ft/s}^2)(0.981\cos 10° - \sin 10°)} = \boxed{152\ \text{ft}} = 46.3\ \text{m}$$

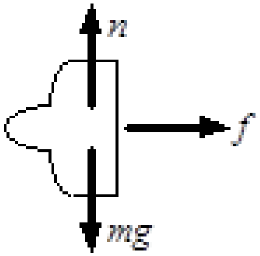
1 mile =5280 ft
1 foot= 0.305 m

If the coefficient of static friction between your coffee cup and the horizontal dashboard of your car is μ s = 0.800, how fast can you drive on a horizontal roadway around a right turn of radius 30.0 m before the cup starts to slide? If you go too fast, in what direction will the cup slide relative to the dashboard?

$$\sum F_y = m a_y : \quad +n - m g = 0$$

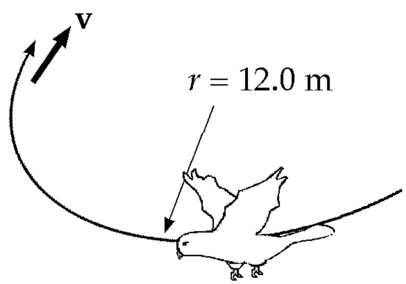
$$\sum F_x = m a_x : \quad f = \frac{m v^2}{r} = \mu_s n = \mu_s m g$$

$$v = \sqrt{\mu_s g r} = \sqrt{0.8\left(9.8 \text{ m/s}^2\right)\left(30 \text{ m}\right)} = \boxed{15.3 \text{ m/s}}$$



If you go too fast the cup will begin sliding straight across the dashboard to the left.

X.16. A hawk flies in a horizontal arc of radius 12.0 m at a constant speed of 4.00 m/s.
(a) Find its centripetal acceleration.
(b) It continues to fly along the same horizontal arc but increases its speed at the rate of 1.20 m/s². Find the acceleration (magnitude and direction) under these conditions.



(a)

$$a_c = \frac{v^2}{r} = \frac{(4.00\ \mathrm{m/s})^2}{12.0\ \mathrm{m}} = \boxed{1.33\ \mathrm{m/s^2}}$$

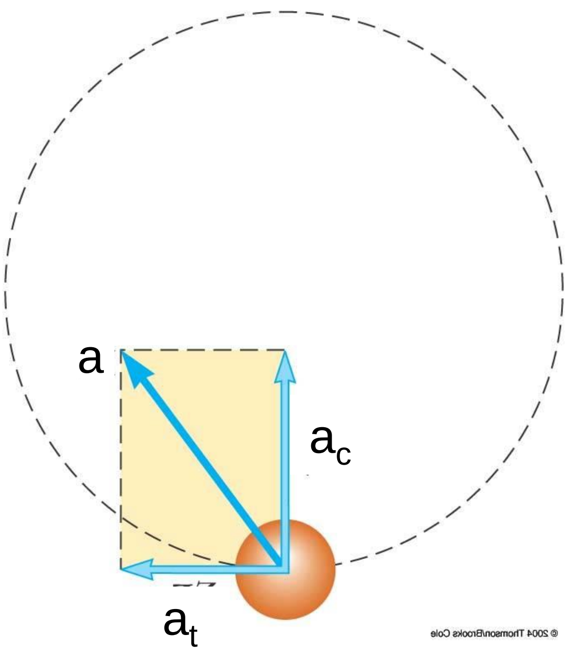
(b)

$$a = \sqrt{a_c^2 + a_t^2}$$

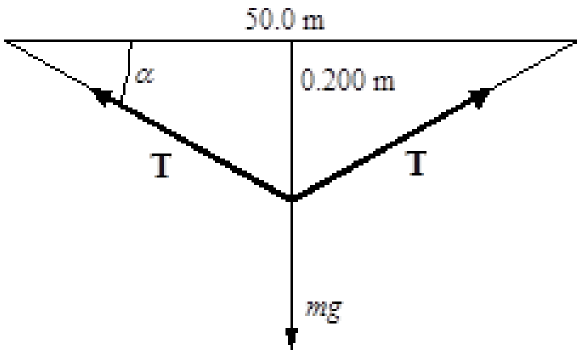
$$a = \sqrt{(1.33)^2 + (1.20)^2} = \boxed{1.79\ \mathrm{m/s^2}}$$

at an angle

$$\theta = \tan^{-1}\left(\frac{a_c}{a_t}\right) = \boxed{48.0^\circ\ \text{inward}}$$



The distance between two telephone poles is 50.0 m. When a 1.00-kg bird lands on the telephone wire midway between the poles, the wire sags 0.200 m. Draw a free-body diagram of the bird. How much tension does the bird produce in the wire? Ignore the weight of the wire.



$$m = 1.00 \text{ kg}$$

$$mg = 9.80 \text{ N}$$

$$\tan\alpha = \frac{0.200 \text{ m}}{25.0 \text{ m}}$$

$$\alpha = 0.458°$$

Balance forces, $\sum F_y = m a_y$ $\quad$ $\sum F_x = m a_x$

$$2T\sin\alpha = m g$$

$$T = \frac{9.80 \text{ N}}{2\sin\alpha} = \boxed{613 \text{ N}}$$

A 650-kg elevator starts from rest. It moves upward for 3.00 s with constant acceleration until it reaches its cruising speed of 1.75 m/s.

(a) What is the average **power** of the elevator motor during this period?

(b) How does this power compare with the motor power when the elevator moves at its cruising speed?

X.40

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X.40

Power

- The time rate of energy transfer is called ***power***
- The average power is given by

$$\overline{P} = \frac{W}{\Delta t}$$

when the method of energy transfer is work

Work Is An Energy Transfer

- This is important for a system approach to solving a problem
- If the work is done on a system and it is positive, energy is transferred to the system
- If the work done on the system is negative, energy is transferred from the system

Work Is An Energy Transfer

- If a system interacts with its environment, this interaction can be described as a transfer of energy across the system boundary
  - This will result in a change in the amount of energy stored in the system

Ways to Transfer Energy Into or Out of A System

- ***Work*** – transfers by applying a force and causing a displacement of the point of application of the force
- ***Mechanical Waves*** – allow a disturbance to propagate through a medium
- ***Heat*** – is driven by a temperature difference between two regions in space

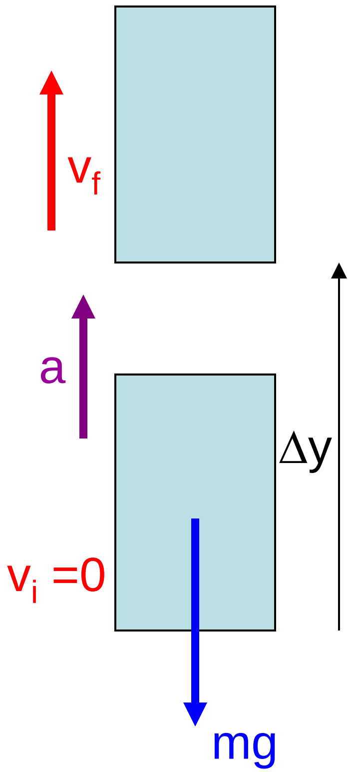
A 650-kg elevator starts from rest. It moves upward for 3.00 s with constant acceleration until it reaches its cruising speed of 1.75 m/s.

(a) What is the average power of the elevator motor during this period?

(b) How does this power compare with the motor power when the elevator moves at its cruising speed?

(a) The distance moved upward in the first 3.00 s is

$$\Delta y = \bar{v}t = \left[\frac{0 + 1.75 \text{ m/s}}{2}\right](3.00 \text{ s}) = 2.63 \text{ m}$$



The motor and the earth's gravity do work on the elevator car:

$$\frac{1}{2}mv_i^2 + W_{motor} + mg\Delta y\cos 180^\circ = \frac{1}{2}mv_f^2$$

$$W_{motor} = \frac{1}{2}(650 \text{ kg})(1.75 \text{ m/s})^2 - 0 + (650 \text{ kg})g(2.63 \text{ m}) = 1.77 \times 10^4 \text{ J}$$

Also, $W = \bar{P}t$

so

$$\bar{P} = \frac{W}{t} = \frac{1.77 \times 10^4 \text{ J}}{3.00 \text{ s}} = \boxed{5.91 \times 10^3 \text{ W}}$$

A 650-kg elevator starts from rest. It moves upward for 3.00 s with constant acceleration until it reaches its cruising speed of 1.75 m/s.

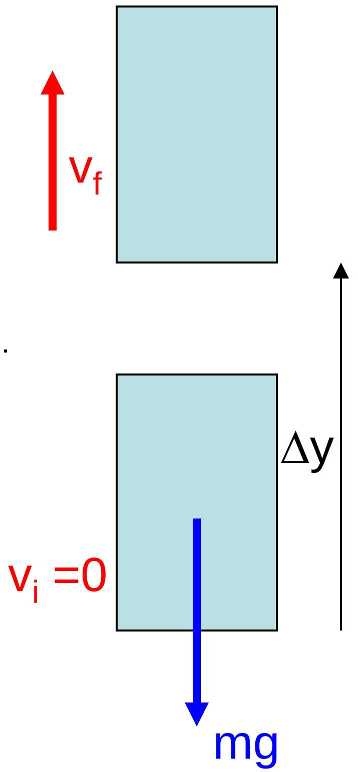
(a) What is the average power of the elevator motor during this period?

(b) How does this power compare with the motor power when the elevator moves at its cruising speed?

When moving upward at constant speed $\left(v = 1.75\ \mathrm{m/s}\right)$

the applied force equals the $\mathrm{weight} = \left(650\ \mathrm{kg}\right)\left(9.80\ \mathrm{m/s^2}\right) = 6.37 \times 10^3\ \mathrm{N}$

$$P = Fv = \left(6.37 \times 10^3\ \mathrm{N}\right)\left(1.75\ \mathrm{m/s}\right) = \boxed{1.11 \times 10^4\ \mathrm{W}}$$



A glider of mass m is **free** to slide along a horizontal air track. It is pushed against a launcher at one end of the track. Model the launcher as a light spring of force constant k, compressed by a distance x. The glider is released from rest.

X.14

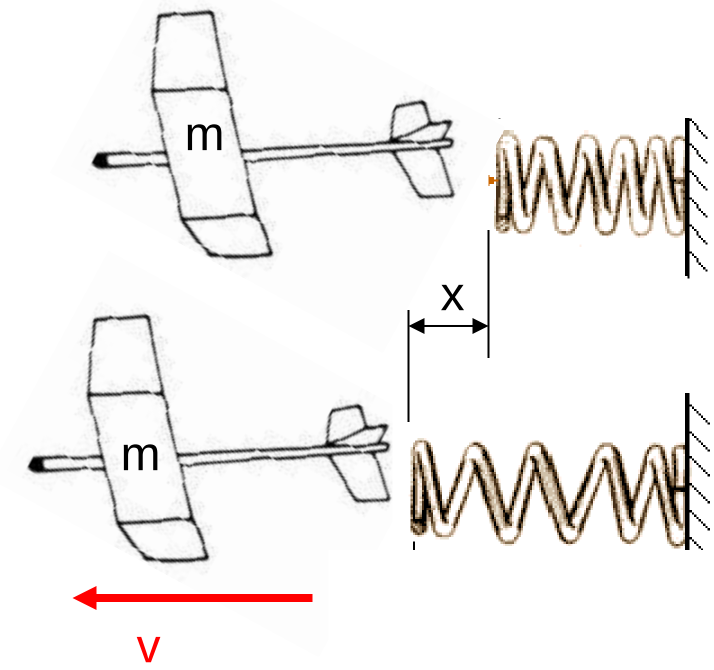
(a) Show that the glider attains a speed $v = x\,(k/m)^{1/2}$.

(b) Does a glider of large or of small mass attain a greater speed?

(c) Show that the impulse imparted to the glider is given by the expression $x(k\,m)^{1/2}$.

(d) Is a greater impulse injected into a large or a small mass?

(e) Is more work done on a large or a small mass?



Conservation of Mechanical Energy

- The mechanical energy of a system is the algebraic sum of the kinetic and potential energies in the system
  - $E_{mech} = K + U$
- The statement of Conservation of Mechanical Energy for an isolated system is

  $K_f + U_f = K_i + U_i$
  - An isolated system is one for which there are no energy transfers across the boundary

Conservation of Energy

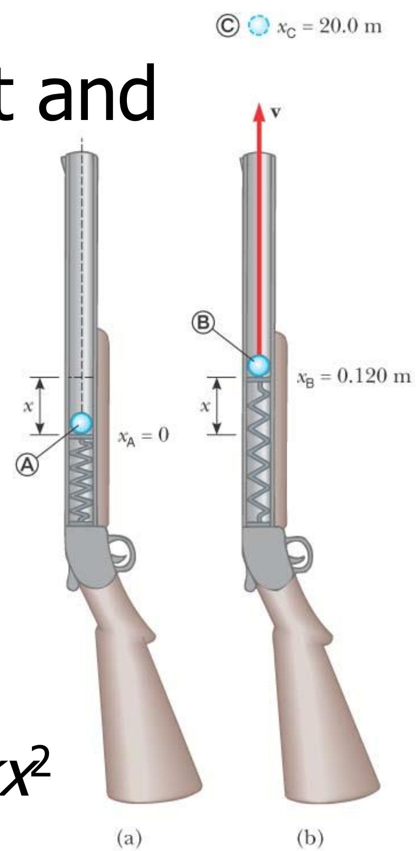
- Choose point A as the initial point and C as the final point
- $E_C = E_A$

  $K_C + U_{gC} + U_{sC} = K_A + U_{gA} + U_{sA}$

  $0 + mgh + 0 = 0 + 0 + \frac{1}{2} kx^2$
- $E_B = E_A$

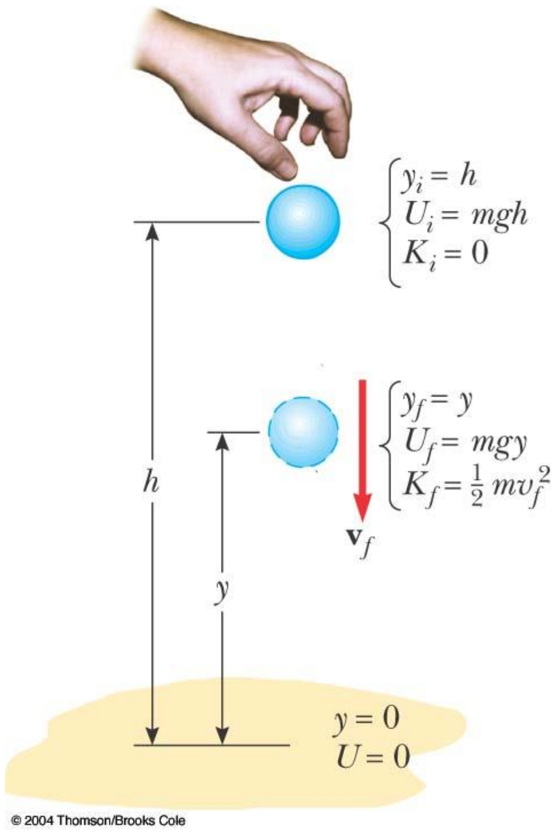
  $K_B + U_{gB} + U_{sB} = K_A + U_{gA} + U_{sA}$

  $1/2\, mv_B^2 + mgx_B + 0 = 0 + 0 + \frac{1}{2} kx^2$



Conservation of Energy

- Initial conditions:
  - $E_i = K_i + U_i = mgh$
  - The ball is dropped, so $K_i = 0$
- The configuration for zero potential energy is the ground
- Conservation rules applied at some point y above the ground gives
  - $\frac{1}{2} mv_f^2 + mgy = mgh$



A glider of mass m is free to slide along a horizontal air track. It is pushed against a launcher at one end of the track. Model the launcher as a light spring of force constant k, compressed by a distance x. The glider is released from rest.

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(c) Show that the impulse imparted to the glider is given by the expression $x(k\,m)^{1/2}$.

(d) Is a greater impulse injected into a large or a small mass?

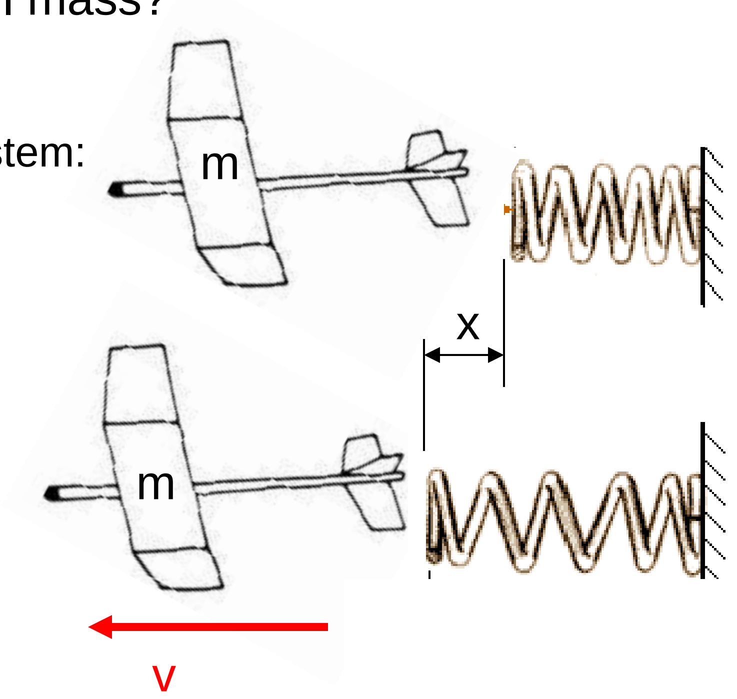
(e) Is more work done on a large or a small mass?

(a) Energy is conserved for the spring-mass system:

$$K_i + U_{si} = K_f + U_{sf}$$

$$0 + \frac{1}{2}kx^2 = \frac{1}{2}mv^2 + 0$$

$$v = x\sqrt{\frac{k}{m}}$$



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(b) Does a glider of large or of small mass attain a greater speed?

(c) Show that the impulse imparted to the glider is given by the expression $x(k\,m)^{1/2}$.

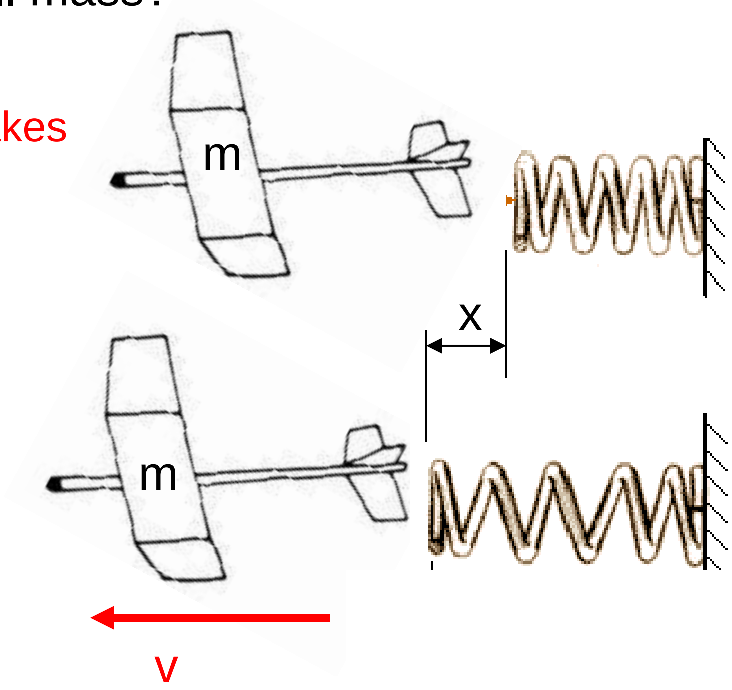
(d) Is a greater impulse injected into a large or a small mass?

(e) Is more work done on a large or a small mass?

(b) From the equation, a **smaller** value of *m* makes

$$v = x\sqrt{\frac{k}{m}}$$

larger.



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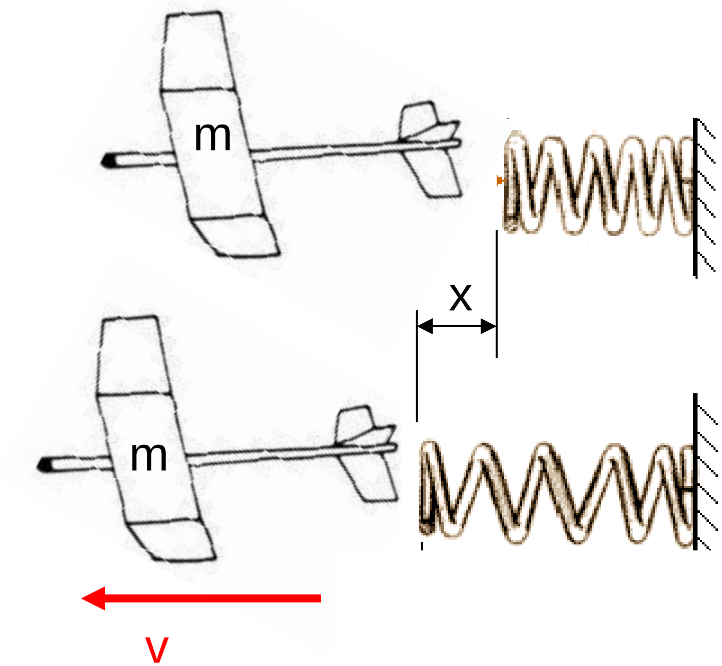

Impulse and Momentum

- From Newton's Second Law, $\mathbf{F} = d\mathbf{p}/dt$
- Solving for $d\mathbf{p}$ gives $d\mathbf{p} = \mathbf{F}dt$
- Integrating to find the change in momentum over some time interval

$$\Delta\mathbf{p} = \mathbf{p}_f - \mathbf{p}_i = \int_{t_i}^{t_f} \mathbf{F}dt = \mathbf{I}$$

- The integral is called the *impulse*, ***I***, of the force **F** acting on an object over Δt

Impulse-Momentum Theorem

- This equation expresses the **impulse-momentum theorem**:The impulse of the force **F** acting on a particle equals the change in the momentum of the particle

This is equivalent to Newton's Second Law

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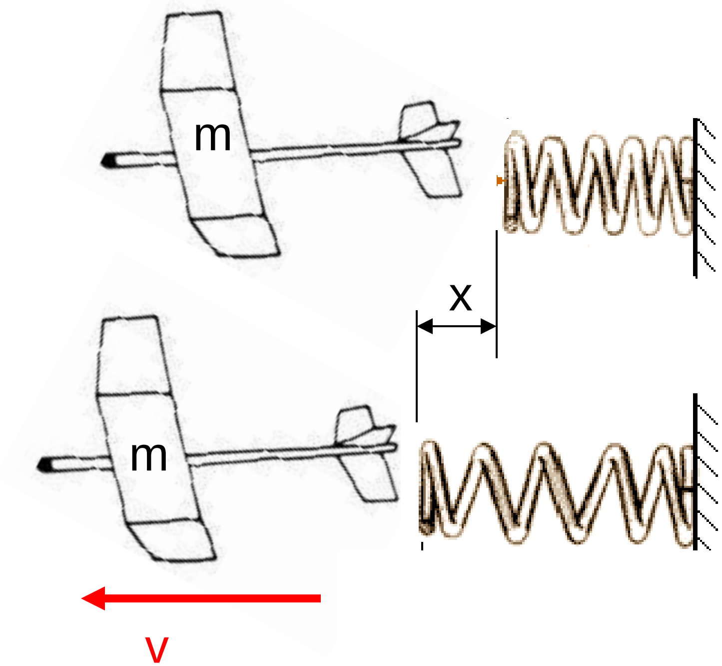
$$I = \left|\mathbf{p}_f - \mathbf{p}_i\right| = m v_f = 0 = m x \sqrt{\frac{k}{m}} = x\sqrt{km}$$



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$$I = x\sqrt{km}$$

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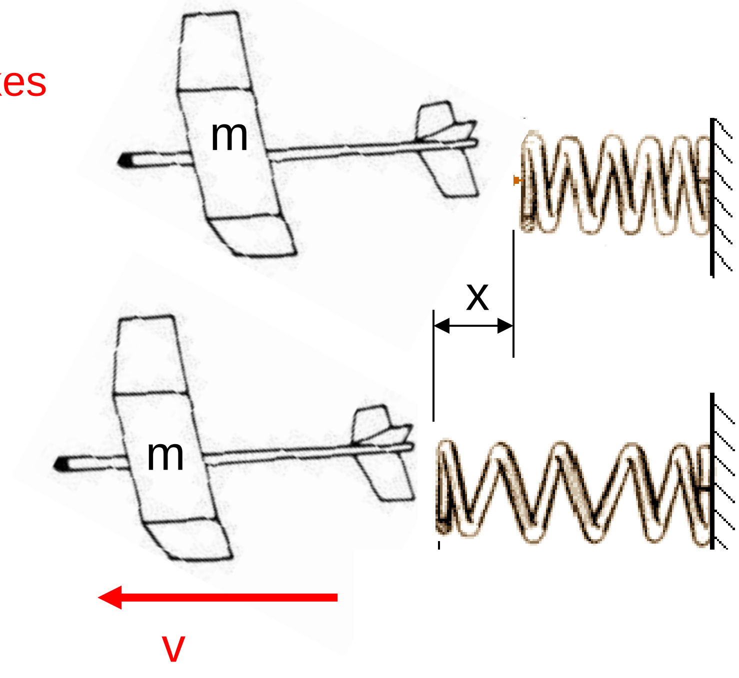

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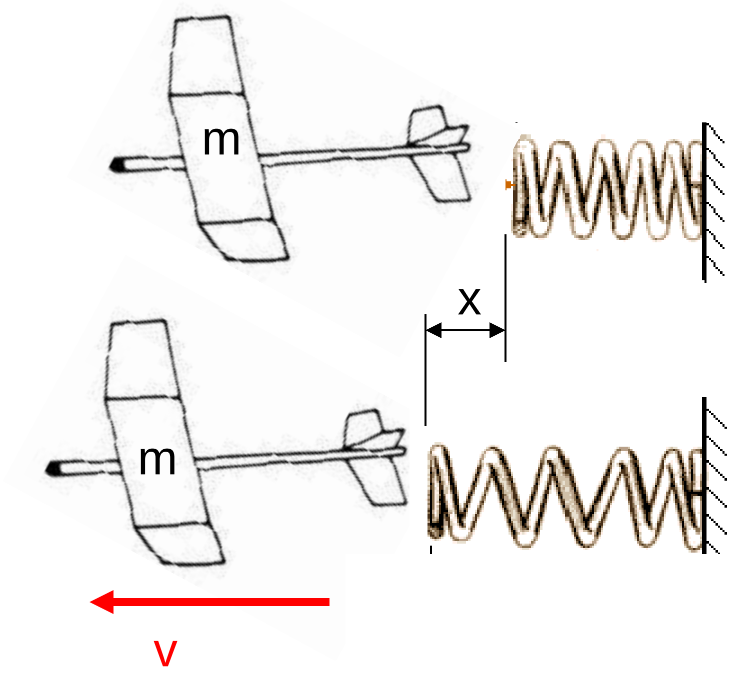

Elastic Potential Energy

- ***Elastic Potential Energy*** is associated with a spring
- The force the spring exerts (on a block, for example) is $F_s = - kx$
- The work done by an external applied force on a spring-block system is
  - $W = ½\ kx_f^2 - ½\ kx_i^2$
  - The work is equal to the difference between the initial and final values of an expression related to the configuration of the system

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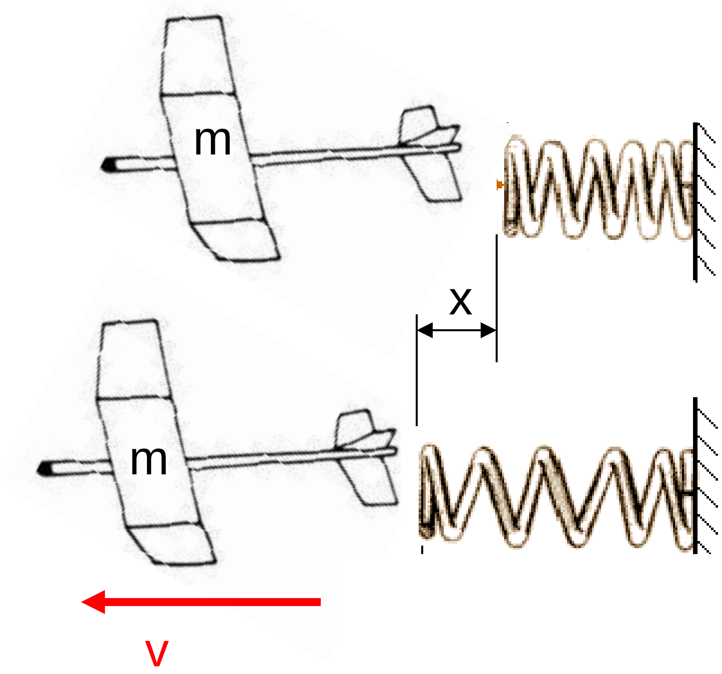

(e) For the glider,

$$W = K_f - K_i = \frac{1}{2} m v^2 - 0 = \frac{1}{2} k x^2$$

$$v = x\sqrt{\frac{k}{m}} \Rightarrow v^2 = x^2\, k/m$$

The mass makes **no difference** to the work