Today 7.2

$\boxed{L22}$

Today 7.2

$\boxed{L22}$

Elastic potential energy

Today 7.2

Monday 7.3 & 7.4

$\boxed{L22}$

Today 7.2

Monday 7.3 & 7.4

L22

Conservative & non-conservative forces

Today 7.2

Monday 7.3 & 7.4

Force & potential energy

$\boxed{L22}$

Elastic potential energy

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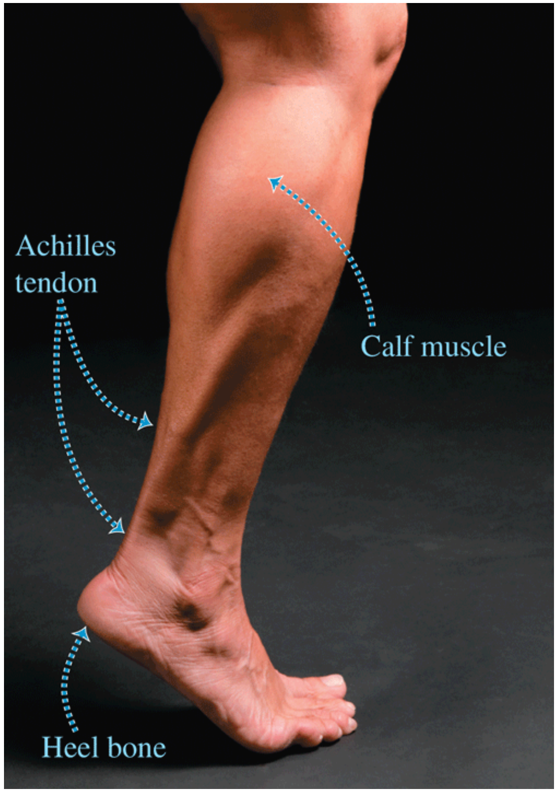
Storage of energy in a deformable object such as a spring or rubber band

Elastic potential energy

Storage of energy in a deformable object such as a spring or rubber band

Tendon acts like a natural spring



The gravitational potential energy is a shared property

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<u>But</u> the elastic potential energy is <u>Not</u> shared.

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But the elastic potential energy is NOT shared.

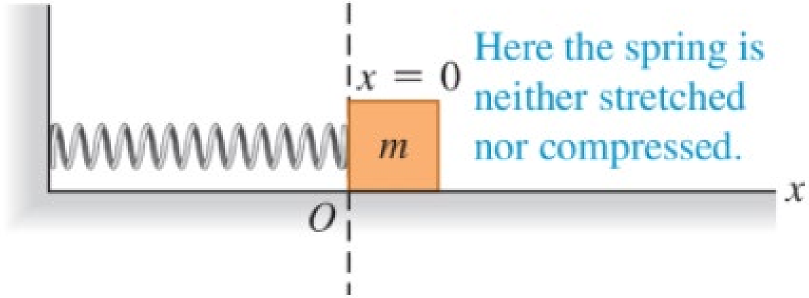
The elastic potential energy is contained in the elastic medium

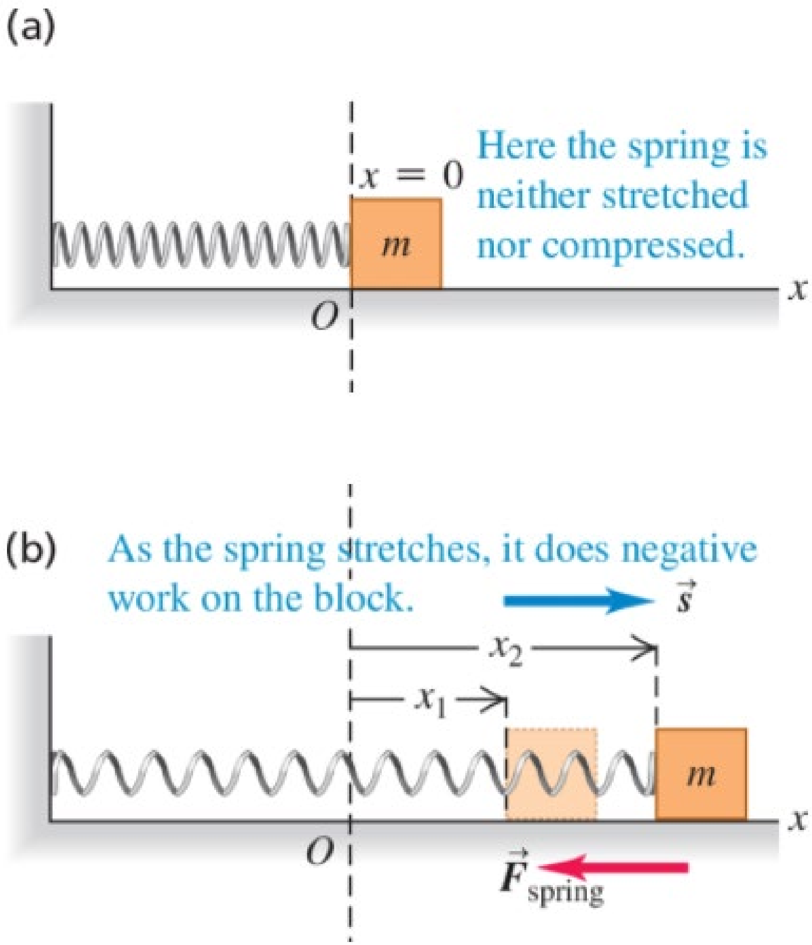
The gravitational potential energy is a shared property

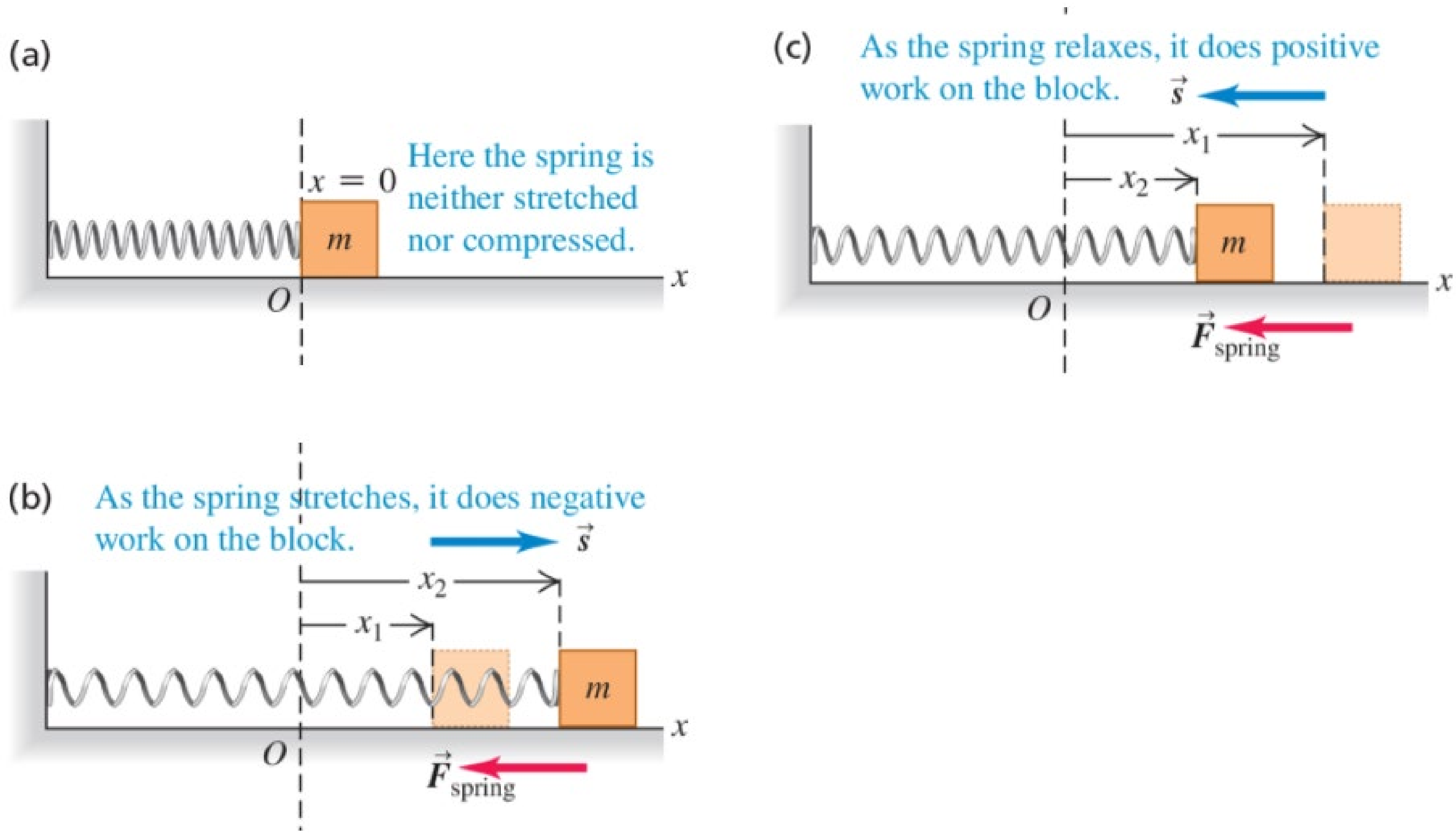
But the elastic potential energy is **NOT** shared.

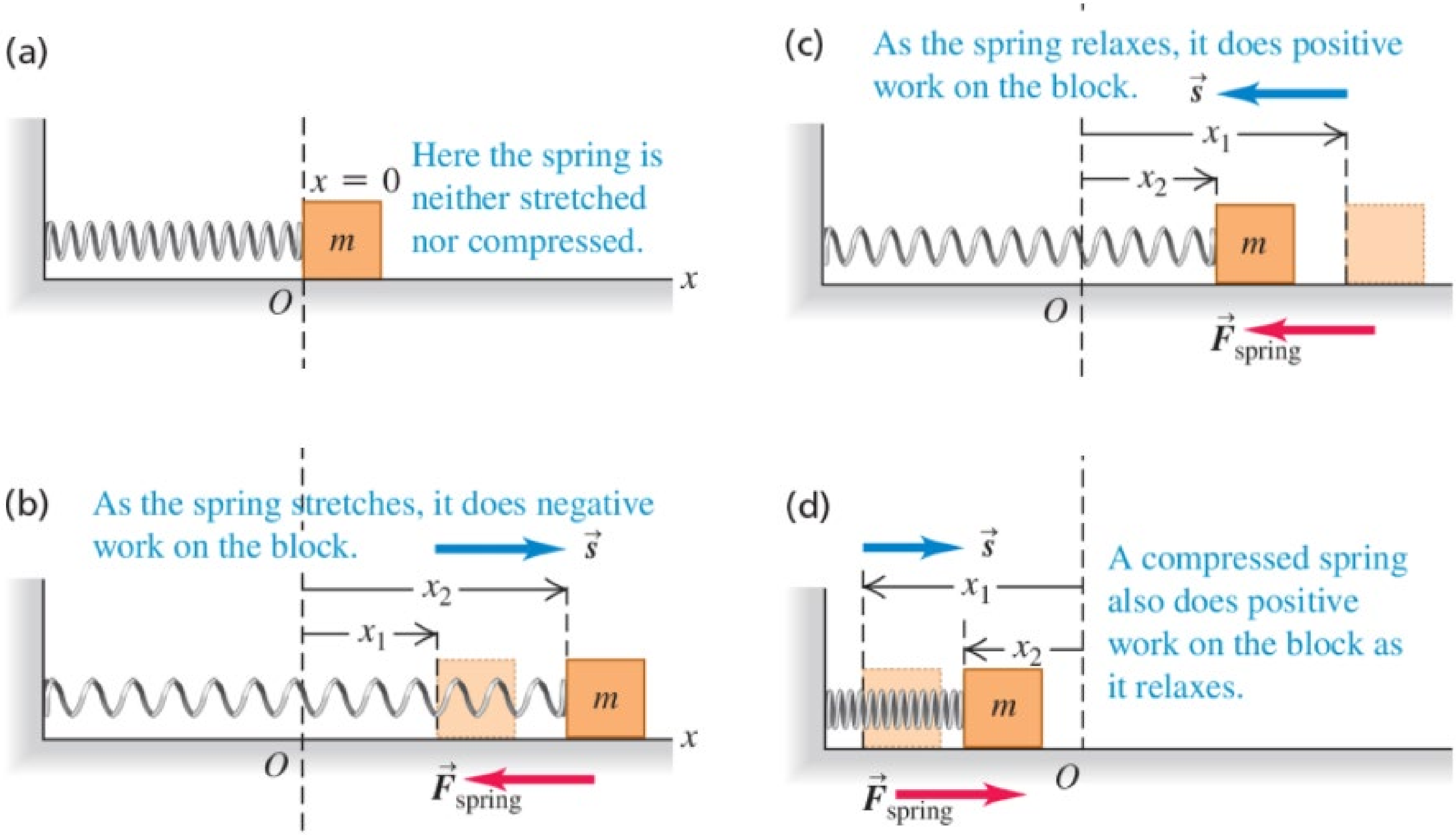
The elastic potential energy is contained in the elastic medium (e.g. spring)

(a)




(a)
x = 0
Here the spring is neither stretched nor compressed.
m
O
x
(b)
As the spring stretches, it does negative work on the block.
$\vec{s}$
x_2
x_1
m
O
x
$\vec{F}_{\text{spring}}$


(a)
Here the spring is neither stretched nor compressed.
x = 0
m
O
x
(b)
As the spring stretches, it does negative work on the block.
s
x2
x1
m
O
x
F spring
(c)
As the spring relaxes, it does positive work on the block.
s
x1
x2
m
O
x
F spring


(a)
Here the spring is neither stretched nor compressed.
x = 0
m
O
x
(b)
As the spring stretches, it does negative work on the block.
s
x2
x1
m
O
x
F spring
(c)
As the spring relaxes, it does positive work on the block.
s
x1
x2
m
O
x
F spring
(d)
s
x1
x2
m
A compressed spring also does positive work on the block as it relaxes.
x
O
F spring

Previously we found that the work done <u>ON</u> a spring is

$$W = \frac{1}{2}k(x_2^2 - x_1^2) \quad \text{, work } \underline{\text{on}} \text{ spring}$$

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$$W = -\frac{1}{2}k(x_2^2 - x_1^2) \quad \text{, work } \underline{\text{by}} \text{ spring}$$

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The work done by a spring just has a sign flip {since Newton's 3rd law flips the direction of the force}

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So if $x_1 = 0$ then $W = -\frac{1}{2}kx^2$

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So if $x_1 = 0$ then $W = -\frac{1}{2}kx^2$ & since

$$U = -W$$

Previously we found that the work done <u>on</u> a spring is

$$W = \frac{1}{2}k(x_2^2 - x_1^2)$$, work <u>on</u> spring

The work done <u>by</u> a spring just has a sign flip {since Newton's 3rd law flips the direction of the force}

$$W = -\frac{1}{2}k(x_2^2 - x_1^2)$$, work <u>by</u> spring

So if $x_1 = 0$ then $W = -\frac{1}{2}kx^2$ & since $U = -W$ then $U_{el} = \frac{1}{2}kx^2$

Elastic potential energy

$$U_{el} = \frac{1}{2}kx^2$$

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Elastic potential energy stored in spring

Elastic potential energy

spring-force constant

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Elongation of spring

Elastic potential energy stored in spring

ASU

Elastic potential energy

spring-force constant

$$U_{el} = \frac{1}{2}kx^2$$

Elongation of spring

($x > 0$ if stretched, $x < 0$ if compressed)

Elastic potential energy stored in spring

$$W_{el} = \frac{1}{2}kx_1^2 - \frac{1}{2}kx_2^2 = U_{el,1} - U_{el,2} = -\Delta U_{el}$$

Work done by the elastic force ...

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Force constant of spring

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Force constant of spring

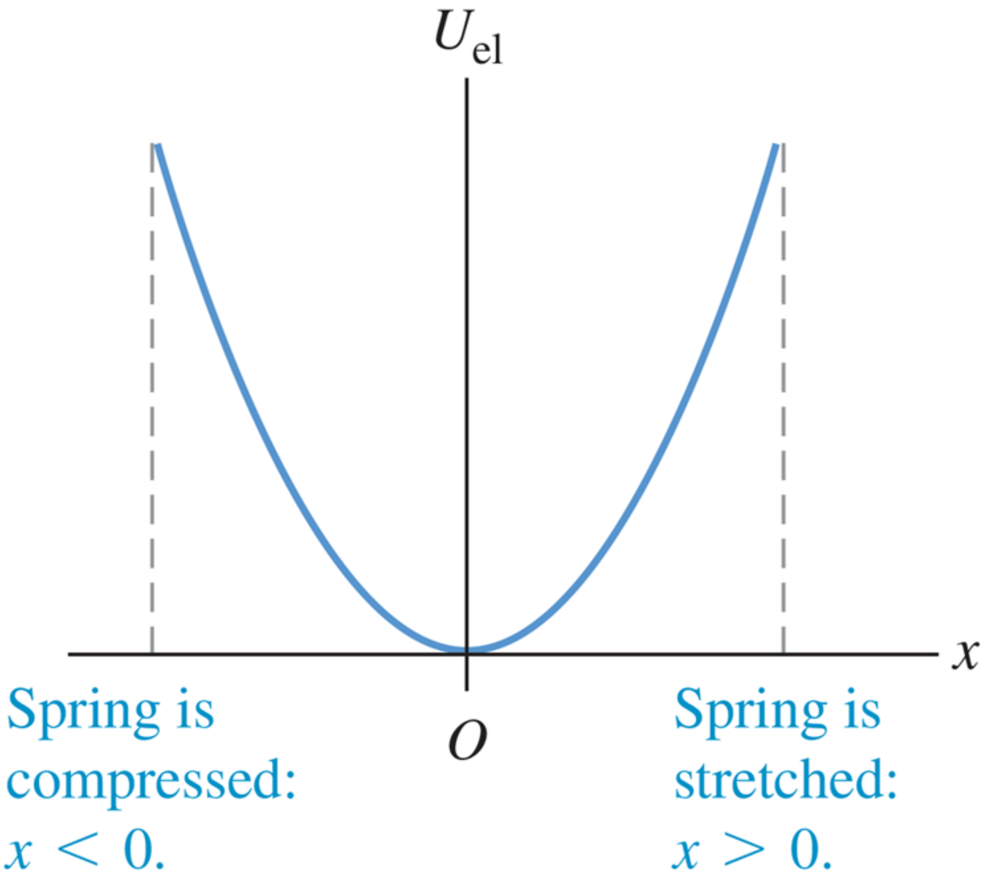
Initial and final elongations of spring

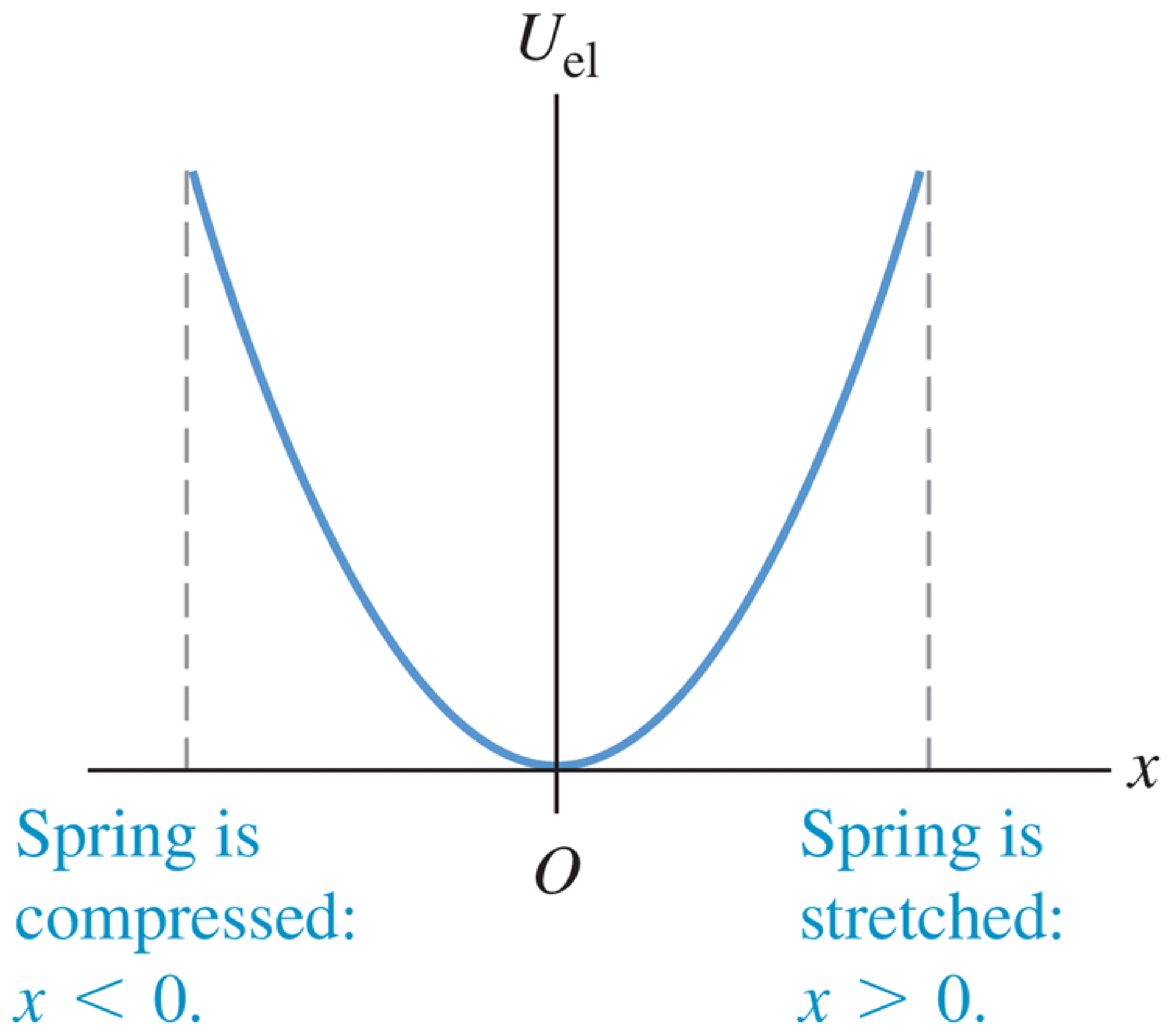
Work done by the elastic force ... ... equals the **negative of the change in elastic potential energy.**

$$W_{\mathrm{el}} = \tfrac{1}{2}kx_1^2 - \tfrac{1}{2}kx_2^2 = U_{\mathrm{el},1} - U_{\mathrm{el},2} = -\Delta U_{\mathrm{el}}$$

Force constant of spring

Initial and final elongations of spring




U_{el}
x
O
Spring is compressed: $x < 0$.
Spring is stretched: $x > 0$.

Note for $U_{el} = \frac{1}{2} k x^2$

we can **not** choose where $x = 0$ is.

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and, as long as you were consistent, your values for U_{el} would be valid

Conservation of energy

Conservation of energy

If only elastic forces performing work

Conservation of energy

If only elastic forces performing work

$$K_1 + U_{el,1} = K_2 + U_{el,2}$$

Conservation of energy

If only elastic forces performing work

$$K_1 + U_{el,1} = K_2 + U_{el,2}$$

&

$$E_{Tot} = K + U_{el}$$

Plus gravity & others

Plus gravity & other

$$W_{grav} + W_{el} + W_{other} = K_2 - K_1$$

Plus gravity & other

$$W_{grav} + W_{el} + W_{other} = K_2 - K_1$$

$$\Rightarrow$$

$$K_1 + U_{g,1} + U_{e,1} + W_{other} = K_2 + U_{g,2} + U_{e,2}$$

Plus gravity & other

$$W_{grav} + W_{el} + W_{other} = K_2 - K_1$$

$$\Rightarrow$$

$$K_1 + U_{g,1} + U_{e,1} + W_{other} = K_2 + U_{g,2} + U_{e,2}$$

Or more simply

Plus gravity & other

$$W_{grav} + W_{el} + W_{other} = K_2 - K_1$$

$$\Rightarrow$$

$$K_1 + U_{g,1} + U_{e,1} + W_{other} = K_2 + U_{g,2} + U_{e,2}$$

Or more simply

$$K_1 + U_1 + W_{other} = K_2 + U_2$$


Gravitational potential energy increases as jumper ascends.
Kinetic energy increases as jumper moves faster.
Elastic potential energy increases when trampoline is stretched.

A glider with mass $m = 0.200\ \mathrm{kg}$ sits on a frictionless, horizontal air track, connected to a spring with force constant $k = 5.00\ \mathrm{N/m}$. You pull on the glider, stretching the spring 0.100 m, and release it from rest. The glider moves back toward its equilibrium position $(x = 0)$. What is its x-velocity when $x = 0.080\ \mathrm{m}$?

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$m = 0.2$ kg, $K = 5$ N/m

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$V_1 = 0$

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$m = 0.2\,kg,\ K = 5\,N/m,\ X_1 = 0.1\,m$

$V_1 = 0$ Find V_2 at $X_2 = 0.08\,m$

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Find v_2 at $x_2 = 0.08\,m$:

$$K_1 + U_1 = K_2 + U_2$$

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$$\cancel{K_1}^{\,0} + U_1 = K_2 + U_2 \Rightarrow K_2 = U_1 - U_2\text{, where}$$

$$K_2 = \tfrac{1}{2} m v_2^2$$

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$$\cancel{K_1} + U_1 = K_2 + U_2 \Rightarrow K_2 = U_1 - U_2,\ \text{where}$$

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$m = 0.2\,kg$, $K = 5\,N/m$, $x_1 = 0.1\,m$

$V_1 = 0$ Find v_2 at $x_2 = 0.08\,m$:

$\cancel{K_1}^{\,0} + U_1 = K_2 + U_2 \Rightarrow K_2 = U_1 - U_2$, where

$K_2 = \frac{1}{2} m v_2^2$, $U_1 = \frac{1}{2} k x_1^2$ & $U_2 = \frac{1}{2} k x_2^2$

A glider with mass $m = 0.200$ kg sits on a frictionless, horizontal air track, connected to a spring with force constant $k = 5.00$ N/m. You pull on the glider, stretching the spring 0.100 m, and release it from rest. The glider moves back toward its equilibrium position $(x = 0)$. What is its x-velocity when $x = 0.080$ m?

$m = 0.2\,kg,\ k = 5\,N/m,\ x_1 = 0.1\,m$

$v_1 = \cancel{0}$

Find v_2 at $x_2 = 0.08\,m$:

$$\cancel{K_1} + U_1 = K_2 + U_2 \Rightarrow K_2 = U_1 - U_2, \text{ where}$$

$$K_2 = \frac{1}{2} m v_2^2,\ U_1 = \frac{1}{2} k x_1^2 \ \&\ U_2 = \frac{1}{2} k x_2^2$$

$$\Rightarrow \frac{1}{2} m v_2^2 = \frac{1}{2} k x_1^2 - \frac{1}{2} k x_2^2$$

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ASU

A glider with mass $m = 0.200$ kg sits on a frictionless, horizontal air track, connected to a spring with force constant $k = 5.00$ N/m. You pull on the glider, stretching the spring 0.100 m, and release it from rest. The glider moves back toward its equilibrium position $(x = 0)$. What is its x-velocity when $x = 0.080$ m?

$m = 0.2\,kg,\ K = 5\,N/m,\ X_1 = 0.1\,m$

$V_1 = 0$

Find V_2 at $X_2 = 0.08\,m$:

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$$K_2 = \tfrac{1}{2} m V_2^2,\ U_1 = \tfrac{1}{2} k X_1^2 \ \&\ U_2 = \tfrac{1}{2} k X_2^2$$

$$\Rightarrow \tfrac{1}{2} m V_2^2 = \tfrac{1}{2} k X_1^2 - \tfrac{1}{2} k X_2^2 \Rightarrow V_2^2 = \left(\frac{k}{m}\right)(X_1^2 - X_2^2)$$

$$\Rightarrow V_2 = \left[\frac{k}{m}(X_1^2 - X_2^2)\right]^{1/2}$$

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$$\Rightarrow V_2 = \left[\tfrac{k}{m}(X_1^2 - X_2^2)\right]^{1/2} = \left[\tfrac{5}{0.2}\left(\tfrac{1}{100} - 0.08^2\right)\right]^{1/2} \tfrac{m}{s}$$

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$m = 0.2\,\text{kg},\ k = 5\,\text{N/m},\ x_1 = 0.1\,\text{m}$

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$$\Rightarrow V_2 = \left[\frac{k}{m}(x_1^2 - x_2^2)\right]^{1/2} = \left[\frac{5}{0.2}\left(\frac{1}{100} - 0.08^2\right)\right]^{1/2} \frac{m}{s}$$

$$\Rightarrow V_2 = 0.3\,\text{m/s}$$

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Find v_2 at $x_2 = 0.08\,m$:

$$\cancel{K_1}^{0} + U_1 = K_2 + U_2 \Rightarrow K_2 = U_1 - U_2, \text{ where}$$

$$K_2 = \tfrac{1}{2} m v_2^2,\ U_1 = \tfrac{1}{2} k x_1^2\ \&\ U_2 = \tfrac{1}{2} k x_2^2$$

$$\Rightarrow \tfrac{1}{2} m v_2^2 = \tfrac{1}{2} k x_1^2 - \tfrac{1}{2} k x_2^2 \Rightarrow \boxed{v_2^2 = \left(\frac{k}{m}\right)(x_1^2 - x_2^2)}$$

$$\Rightarrow V_2 = \left[\frac{k}{m}(x_1^2 - x_2^2)\right]^{1/2} = \left[\frac{5}{0.2}\left(\frac{1}{100} - 0.08^2\right)\right]^{1/2} \frac{m}{s}$$

$$\Rightarrow V_2 = 0.3\,m/s$$

could be + or −

Suppose the glider in Example 7.7 is initially at rest at $x = 0$, with the spring unstretched. You then push on the glider with a constant force $\vec{F}$ (magnitude $0.610\ \mathrm{N}$) in the $+x$-direction. What is the glider's velocity when it has moved to $x = 0.100\ \mathrm{m}$?

ASU

Suppose the glider in Example 7.7 is initially at rest at $x = 0$, with the spring unstretched. You then push on the glider with a constant force $\vec{F}$ (magnitude $0.610\ \mathrm{N}$) in the $+x$-direction. What is the glider's velocity when it has moved to $x = 0.100\ \mathrm{m}$? $V_1 = \emptyset$,

$X_1 = \emptyset$,

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$x_1 = 0$, $\vec{F} = \hat{i}\,0.610N$

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$x_1 = 0$, $\vec{F} = \hat{i}\,0.610N$

Find v_2 when $x_2 = 0.1m$

Suppose the glider in Example 7.7 is initially at rest at $x = 0$, with the spring unstretched. You then push on the glider with a constant force $\vec{F}$ (magnitude 0.610 N) in the $+x$-direction. What is the glider's velocity when it has moved to $x = 0.100$ m? $V_1 = 0$,

$x_1 = 0$, $\vec{F} = \hat{i}\,0.610N$

Find v_2 when $x_2 = 0.1m$:

$$K_1 + U_1 + W_{other} = K_2 + U_2$$

Suppose the glider in Example 7.7 is initially at rest at $x = 0$, with the spring unstretched. You then push on the glider with a constant force $\vec{F}$ (magnitude 0.610 N) in the $+x$-direction. What is the glider's velocity when it has moved to $x = 0.100\ \mathrm{m}$? $V_1 = 0$,

$X_1 = 0$, $\vec{F} = \hat{i}\, 0.610\mathrm{N}$

Find V_2 when $X_2 = 0.1\mathrm{m}$:

$$\cancelto{0}{K_1} + \cancelto{0}{U_1} + W_{other} = K_2 + U_2$$

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Find v_2 when $x_2 = 0.1m$:

$$\cancelto{0}{K_1} + \cancelto{0}{U_1} + W_{other} = K_2 + U_2, \text{ where}$$

$$W_{other} = F(x_2 - x_1)$$

Suppose the glider in Example 7.7 is initially at rest at $x = 0$, with the spring unstretched. You then push on the glider with a constant force $\vec{F}$ (magnitude 0.610 N) in the $+x$-direction. What is the glider's velocity when it has moved to $x = 0.100$ m? $V_1 = 0$,

$x_1 = 0$, $\vec{F} = \hat{i}\,0.610N$

Find v_2 when $x_2 = 0.1m$:

$\cancel{K_1}^{0} + \cancel{U_1}^{0} + W_{other} = K_2 + U_2$, where

$W_{other} = F(x_2 - x_1)$, $K_2 = \frac{1}{2}mv_2^2$

Suppose the glider in Example 7.7 is initially at rest at $x = 0$, with the spring unstretched. You then push on the glider with a constant force $\vec{F}$ (magnitude 0.610 N) in the $+x$-direction. What is the glider's velocity when it has moved to $x = 0.100$ m? $V_1 = 0$,

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Find v_2 when $x_2 = 0.1m$:

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$x_1 = 0$, $\vec{F} = \hat{i}\,0.610N$

Find V_2 when $x_2 = 0.1m$:

$$\cancelto{0}{K_1} + \cancelto{0}{U_1} + W_{other} = K_2 + U_2, \text{ where}$$

$$W_{other} = F(x_2 - \cancelto{0}{x_1}),\; K_2 = \tfrac{1}{2}mV_2^2 \;\&\; U_2 = \tfrac{1}{2}kx_2^2$$

$$\text{so}\quad K_2 = W_{other} - U_2 \Rightarrow \tfrac{1}{2}mV_2^2 = Fx_2 - \tfrac{1}{2}kx_2^2$$

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$x_1 = 0$, $\vec{F} = \hat{i}\,0.610\,\text{N}$

$\underline{\text{Find } v_2 \text{ when } x_2 = 0.1\,\text{m}:}$

$$\cancelto{0}{K_1} + \cancelto{0}{U_1} + W_{\text{other}} = K_2 + U_2, \text{ where}$$

$$W_{\text{other}} = F(x_2 - \cancelto{0}{x_1}), \quad K_2 = \tfrac{1}{2} m v_2^2 \;\; \& \;\; U_2 = \tfrac{1}{2} k x_2^2$$

so $K_2 = W_{\text{other}} - U_2 \Rightarrow \tfrac{1}{2} m v_2^2 = F x_2 - \tfrac{1}{2} k x_2^2$

$$\Rightarrow \quad v_2^2 = \frac{2F}{m} x_2 - \frac{k}{m} x_2^2$$

Suppose the glider in Example 7.7 is initially at rest at $x = 0$, with the spring unstretched. You then push on the glider with a constant force $\vec{F}$ (magnitude 0.610 N) in the $+x$-direction. What is the glider's velocity when it has moved to $x = 0.100$ m? $V_1 = 0$,

$X_1 = 0$, $\vec{F} = \hat{i}\, 0.610N$

Find V_2 when $X_2 = 0.1m$:

$\cancel{K_1}^{\,0} + \cancel{U_1}^{\,0} + W_{other} = K_2 + U_2$, where

$W_{other} = F(X_2 - \cancel{X_1}^{\,0})$, $K_2 = \frac{1}{2}mV_2^2$ & $U_2 = \frac{1}{2}kX_2^2$

so $K_2 = W_{other} - U_2 \Rightarrow \frac{1}{2}mV_2^2 = FX_2 - \frac{1}{2}kX_2^2$

$\Rightarrow \quad V_2 = \left[\frac{2F}{m}X_2 - \frac{k}{m}X_2^2\right]^{1/2}$

ASU

Suppose the glider in Example 7.7 is initially at rest at $x = 0$, with the spring unstretched. You then push on the glider with a constant force $\vec{F}$ (magnitude 0.610 N) in the $+x$-direction. What is the glider's velocity when it has moved to $x = 0.100$ m? $V_1 = 0$,

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$$\Rightarrow V_2 = \left[\frac{2F}{m}X_2 - \frac{k}{m}X_2^2\right]^{1/2} = \left[\frac{1.22}{0.2}*0.1 - \frac{5}{0.2}*0.1^2\right]^{1/2}\frac{m}{s}$$

Suppose the glider in Example 7.7 is initially at rest at $x = 0$, with the spring unstretched. You then push on the glider with a constant force $\vec{F}$ (magnitude 0.610 N) in the $+x$-direction. What is the glider's velocity when it has moved to $x = 0.100$ m? $V_1 = 0$,

$x_1 = 0$, $\vec{F} = \hat{i}\,0.610N$

Find V_2 when $x_2 = 0.1m$:

$$\cancel{K_1} + \cancel{U_1} + W_{other} = K_2 + U_2 \text{, where}$$

$$W_{other} = F(x_2 - \cancel{x_1}),\ K_2 = \tfrac{1}{2}mV_2^2 \ \& \ U_2 = \tfrac{1}{2}kx_2^2$$

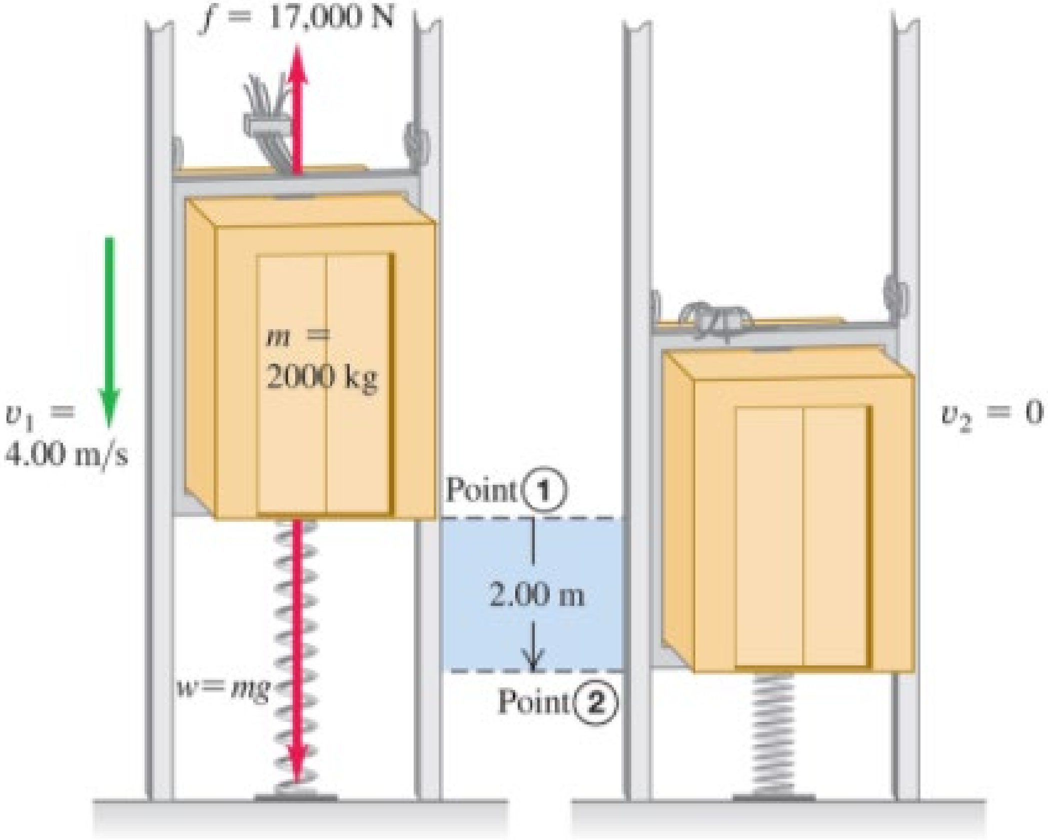
so $K_2 = W_{other} - U_2 \Rightarrow \tfrac{1}{2}mV_2^2 = Fx_2 - \tfrac{1}{2}kx_2^2$

$$\Rightarrow V_2 = \left[\frac{2F}{m}x_2 - \frac{k}{m}x_2^2\right]^{1/2} = \left[\frac{1.22}{0.2} * 0.1 - \frac{5}{0.2} * 0.1^2\right]^{1/2} \frac{m}{s}$$

$$\Rightarrow \boxed{V_2 = 0.591\ m/s}$$

ASU

A 2000 kg $(19,600\ N)$ elevator with broken cables in a test rig is falling at $4.00\ \mathrm{m}/s$ when it contacts a cushioning spring at the bottom of the shaft. The spring is intended to stop the elevator, compressing 2.00 m as it does so (Fig. 7.17). During the motion a safety clamp applies a constant 17,000 N friction force to the elevator. What is the necessary force constant k for the spring?



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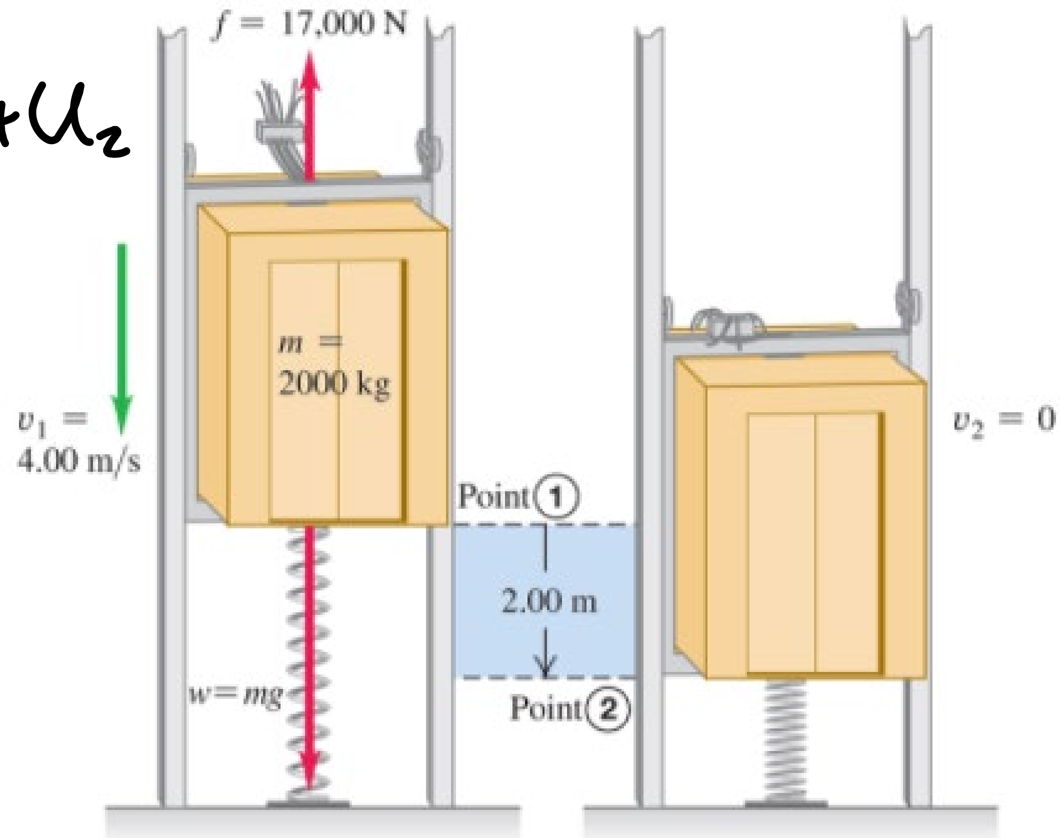
$K_1 + U_1 + W_{other} = K_2 + U_2$



ASU

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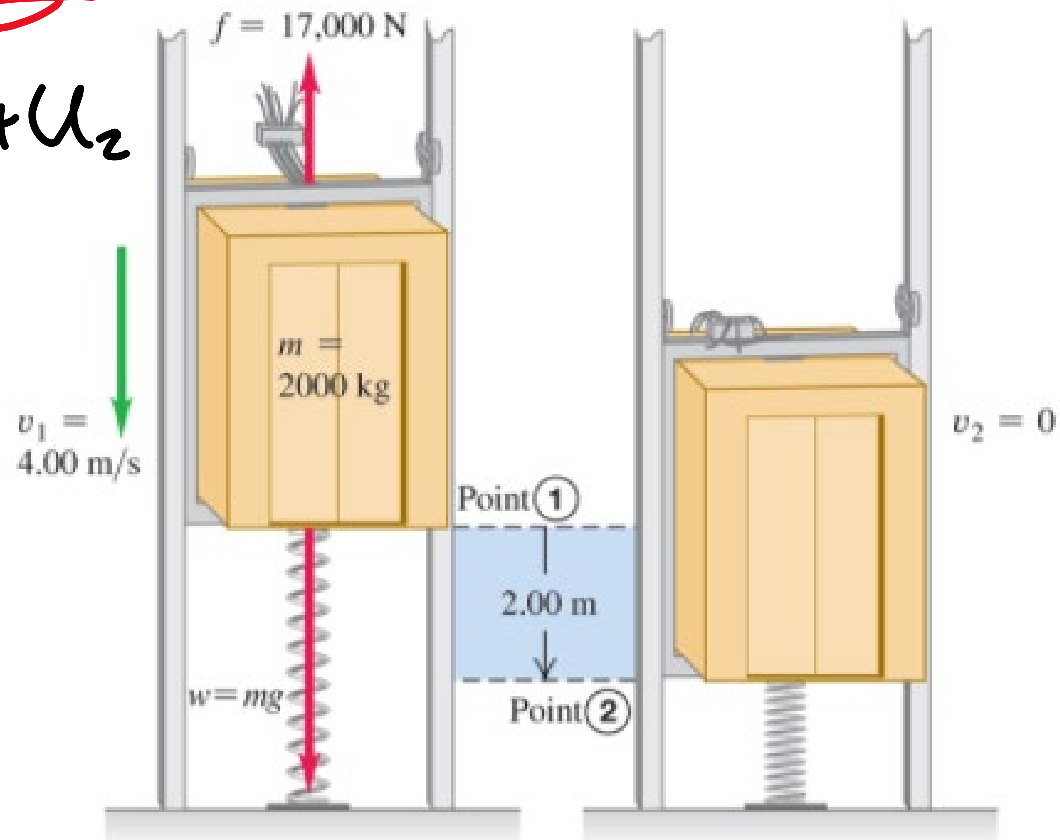
$$K_1 + U_1 + W_{other} = \overset{0}{\cancel{K_2}} + U_2$$

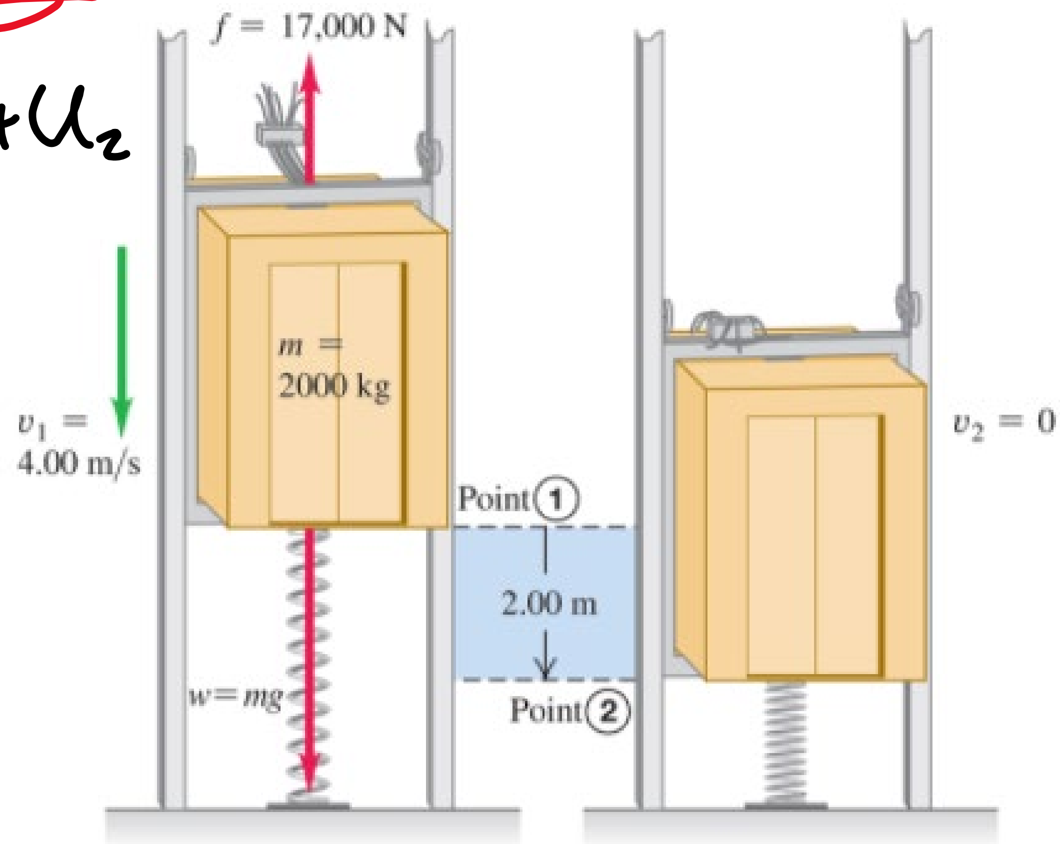


A 2000 kg (19, 600 N) elevator with broken cables in a test rig is falling at 4.00 m/s when it contacts a cushioning spring at the bottom of the shaft. The spring is intended to stop the elevator, compressing 2.00 m as it does so (Fig. 7.17). During the motion a safety clamp applies a constant 17,000 N friction force to the elevator. What is the necessary force constant k for the spring?

$$K_1 + U_1 + W_{other} = \cancel{K_2} + U_2$$

so

$$\frac{1}{2}ky^2 = \frac{1}{2}mv_1^2 + mgy - Fy$$



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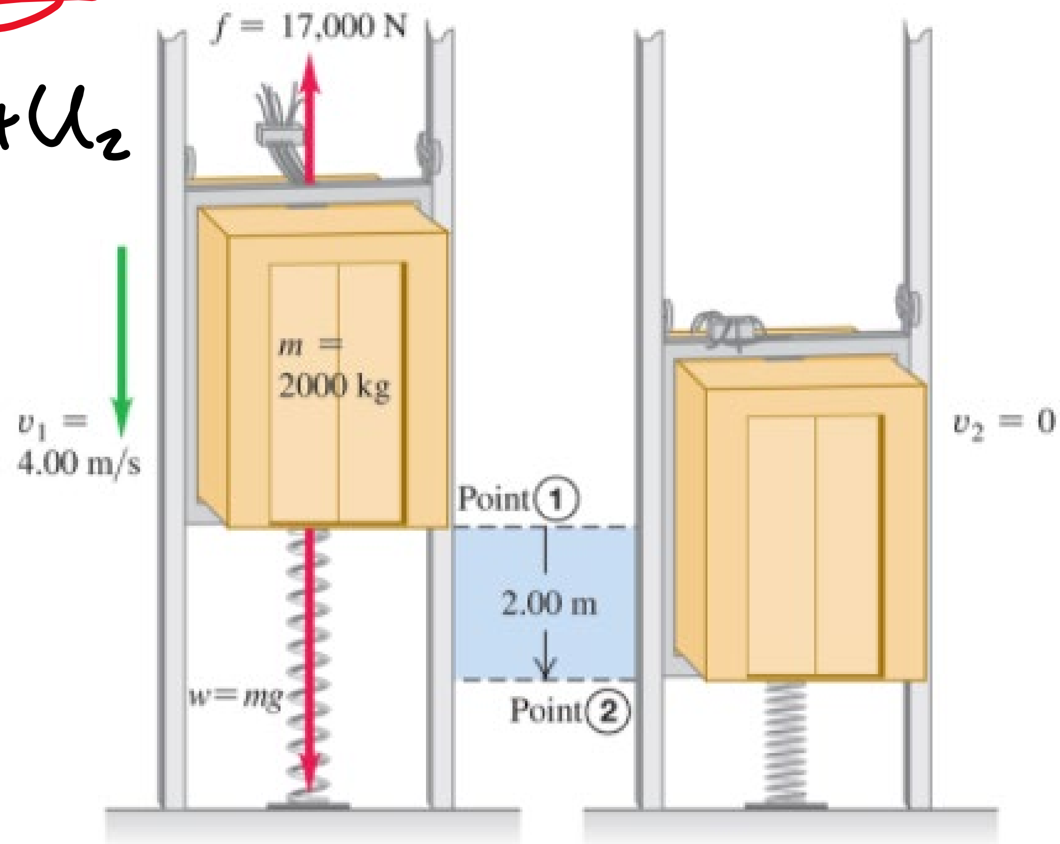

$$K_1 + U_1 + W_{other} = \cancel{K_2} + U_2$$

so

$$\frac{1}{2}ky^2 = \frac{1}{2}mv_1^2 + mgy - Fy$$

$\Rightarrow$

$$K = \frac{m}{y^2}V_1^2 + \frac{mg}{y} - \frac{F}{y}$$

A 2000 kg $(19,600\ N)$ elevator with broken cables in a test rig is falling at $4.00\ \mathrm{m}/s$ when it contacts a cushioning spring at the bottom of the shaft. The spring is intended to stop the elevator, compressing 2.00 m as it does so (Fig. 7.17). During the motion a safety clamp applies a constant 17,000 N friction force to the elevator. What is the necessary force constant k for the spring?

$$K_1 + U_1 + W_{other} = \cancel{K_2} + U_2$$

So

$$\frac{1}{2}ky^2 = \frac{1}{2}mv_1^2 + mgy - Fy$$

$$\Rightarrow$$

$$k = \frac{m}{y^2}v_1^2 + \left(\frac{mg}{y} - \frac{F}{y}\right)2$$

$$\Rightarrow k = \left[\frac{2000}{4}16 + \left(\frac{2000 \times 9.8}{2} - \frac{17000}{2}\right)2\right]\frac{N}{m}$$

A 2000 kg (19,600 N) elevator with broken cables in a test rig is falling at 4.00 m/s when it contacts a cushioning spring at the bottom of the shaft. The spring is intended to stop the elevator, compressing 2.00 m as it does so (Fig. 7.17). During the motion a safety clamp applies a constant 17,000 N friction force to the elevator. What is the necessary force constant k for the spring?

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$\Rightarrow$

$$k = \frac{m}{y^2}v_1^2 + \left(\frac{mg}{y} - \frac{F}{y}\right)2$$

$$\Rightarrow k = \left[\frac{2000}{4}16 + \left(\frac{2000 \times 9.8}{2} - \frac{17000}{2}\right)2\right]\frac{N}{m} = \boxed{10600 N/m}$$