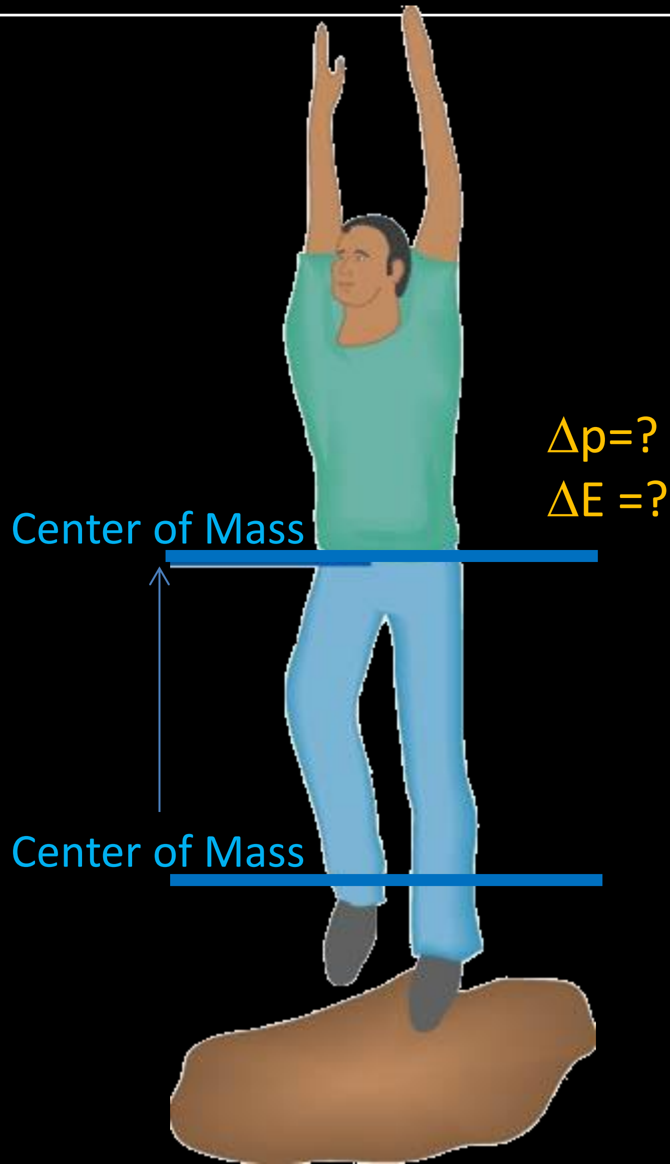
Mon.	**9.4-.5 (.9)** The "Point Particle" approximation	RE 9.c
Tues.		EP8, HW9: Ch 9 Pr's 34, 40, 43
Wed.	**10.1-.4** Introducing Collisions **Quiz 9**	**RE 10.a**
Lab	**L8** Multi-particle Systems	
Fri.	**10.6-.8** Scattering	**RE 10.b**



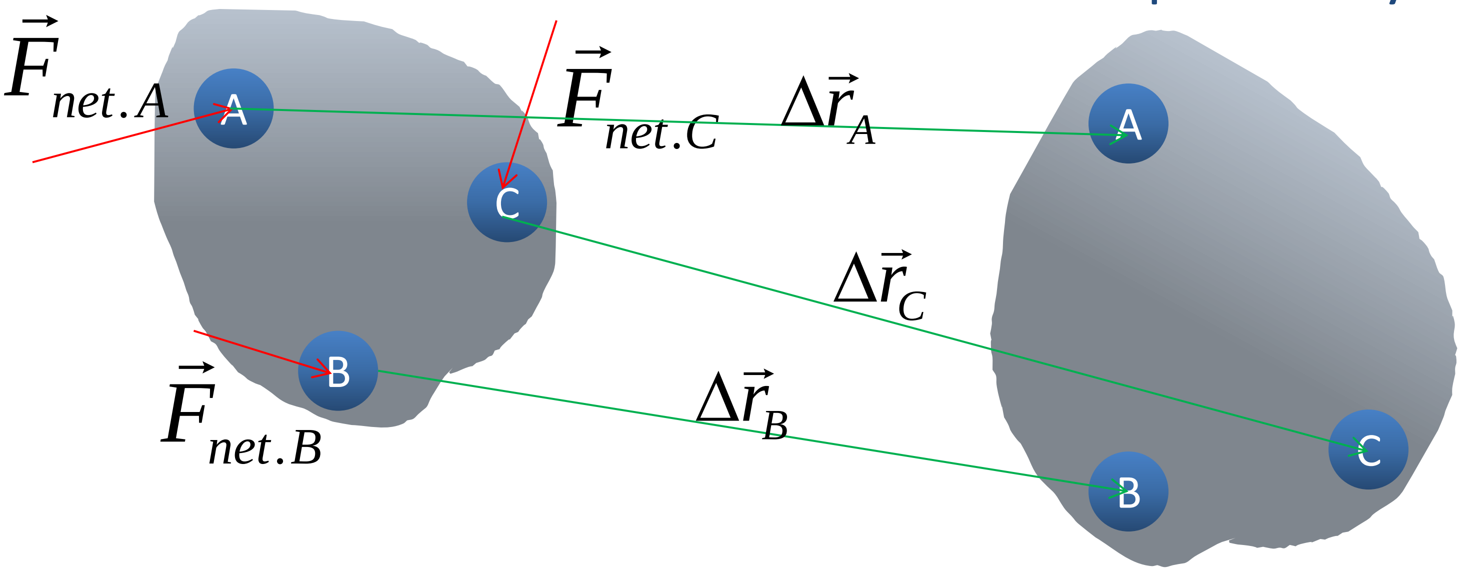
Work and Translational Kinetic Energy

$$W_{net} = \Delta E_{\text{system}}$$

$$W_{net} = \Delta K_{\text{translational}} + \Delta E_{\text{internal}}$$

$$W_{net} = \Delta\left(\tfrac{1}{2} M v_{cm}^2\right) + \Delta E_{\text{internal}}$$

What is the net work done on a multi-particle system?

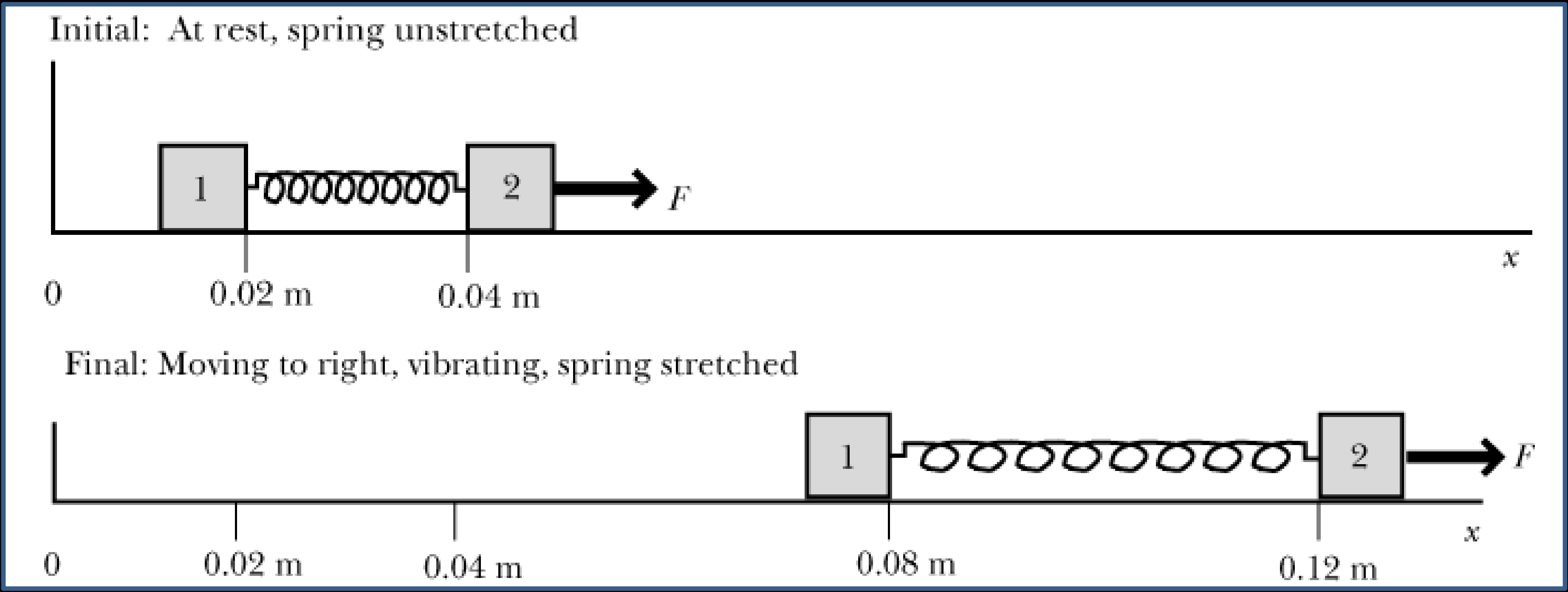


$$W_{net} = W_{net.A} + W_{net.B} + W_{net.C} = \int \vec{F}_{net.A} \cdot d\vec{r}_A + \int \vec{F}_{net.B} \cdot d\vec{r}_B + \int \vec{F}_{net.C} \cdot d\vec{r}_C$$

Each integral for each external force over the displacement of *it's* point of application.

$$W_{net} = \sum_{particles} \int \vec{F}_{net.particle} \cdot \underline{d\vec{r}_{particle}}$$

Over what distance was the force applied?



a) 0.03 m **b) 0.04 m** **c) 0.07 m** **d) 0.08 m** **e) 0.10 m**

Assume no friction; say you pulled horizontally with a constant 0.5N force, then the total work done on the system **/ total change in energy of the system** was

$$\Delta E_{\text{system}} = W_{net}$$

$$\Delta E_{system} = \int \vec{F}_{hand} \cdot d\vec{r}_{hand}$$

$$\Delta E_{system} = F_{hand} \Delta r_{hand}$$

$$\Delta E_{system} = (0.5N)(0.08m) \quad = 0.04Nm$$

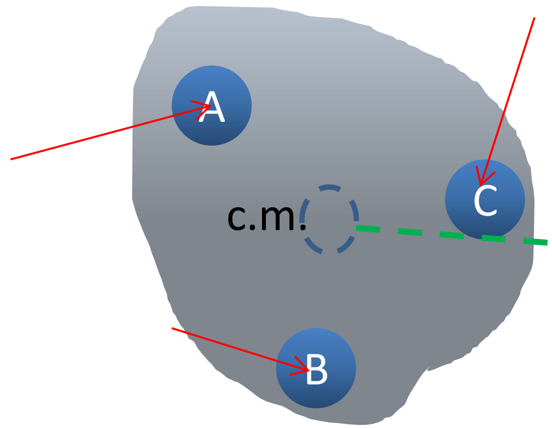
Work and Translational Kinetic Energy

$$W_{net} = \Delta E_{\text{system}}$$

$$W_{net} = \Delta K_{\text{translational}} + \Delta E_{\text{internal}}$$

$$W_{net} = \Delta\left(\tfrac{1}{2} M v_{cm}^2\right) + \Delta E_{\text{internal}}$$

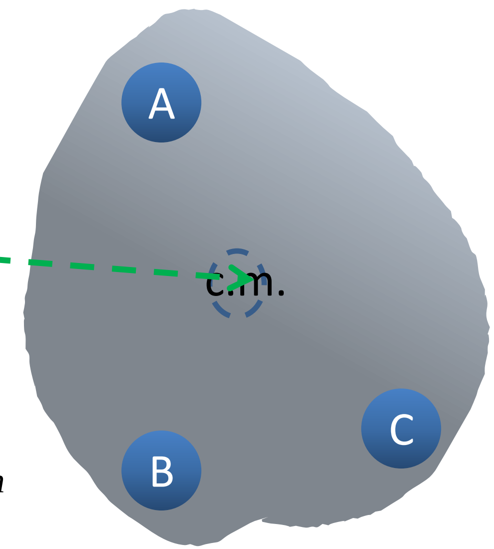
How is that split between translational and internal energy?



$$\vec{F}_{net} = \frac{d\vec{p}_{total}}{dt} \approx M \frac{d\vec{v}_{cm}}{dt}$$

$$\int \vec{F}_{net} \cdot d\vec{r}_{cm} = \int M \frac{d\vec{v}_{cm}}{dt} \cdot d\vec{r}_{cm}$$

$$\int \vec{F}_{net} \cdot d\vec{r}_{cm} = \int M d\vec{v}_{cm} \cdot \frac{d\vec{r}_{cm}}{dt}$$



$$\int \vec{F}_{net} \cdot d\vec{r}_{cm} = \int M\vec{v}_{cm} \cdot d\vec{v}_{cm}$$

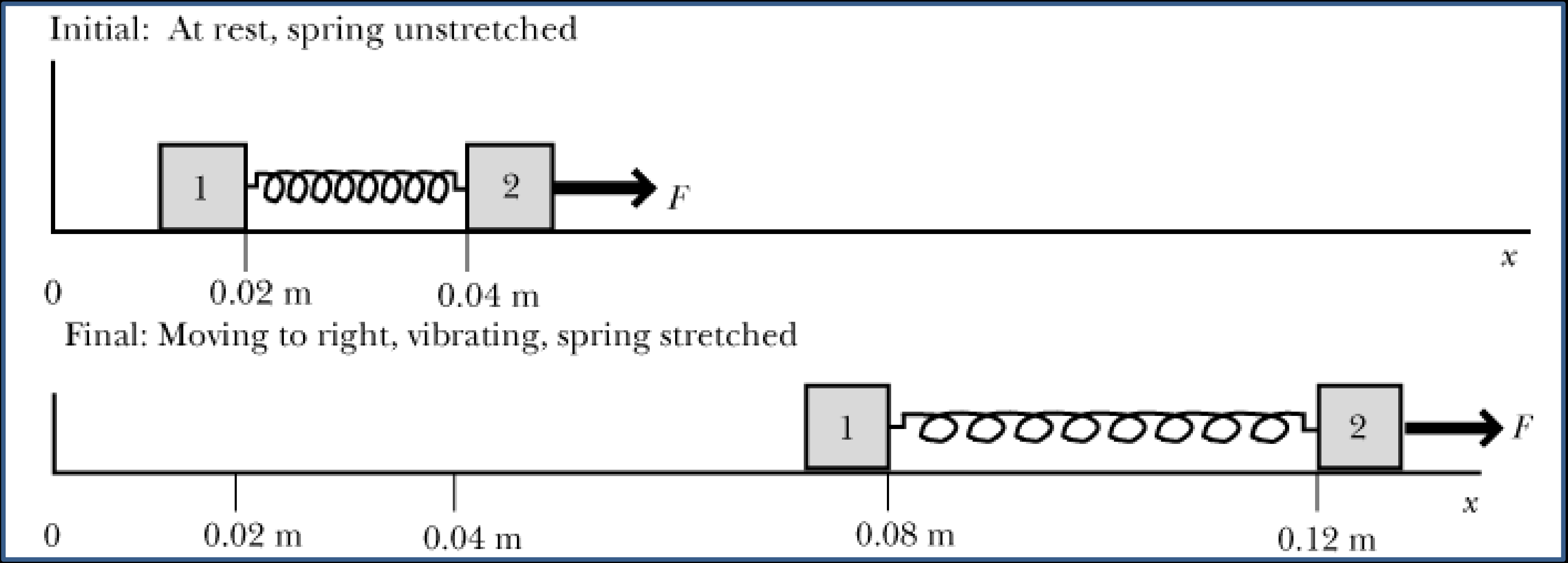
$$\int \vec{F}_{net} \cdot d\vec{r}_{cm} = \int M\vec{v}_{cm} \cdot d\vec{v}_{cm}$$

$$\int \vec{F}_{net} \cdot d\vec{r}_{cm} = \Delta\left(\tfrac{1}{2} M v_{cm}^2\right)$$

$$"W_{cm}" = \Delta K_{translational}$$

Just like for a point particle

If both blocks have the same mass, then through what distance did the center of mass travel while the force acted?



a) 0.03 m **b) 0.04 m** **c) 0.07 m** **d) 0.08 m** **e) 0.10 m**

Assume no friction; say both blocks have the same mass, 0.1 kg (and the spring is much less massive), and you pulled horizontally with a constant 0.5N force, then the **change in translational kinetic energy** associated with the center of mass motion was

$$\Delta K_{trans} = \int \vec{F}_{net} \cdot d\vec{r}_{cm}$$

$$\Delta K_{trans} = F_{hand} \Delta r_{cm}$$

$$\Delta K_{trans} = (0.5N)(0.07m) = 0.035Nm$$

What is the center of mass's final speed?

$$\Delta K_{trans} = \tfrac{1}{2} m_{system} v_{cm.f}^2 - \tfrac{1}{2} m_{system} v_{cm.i}^2$$

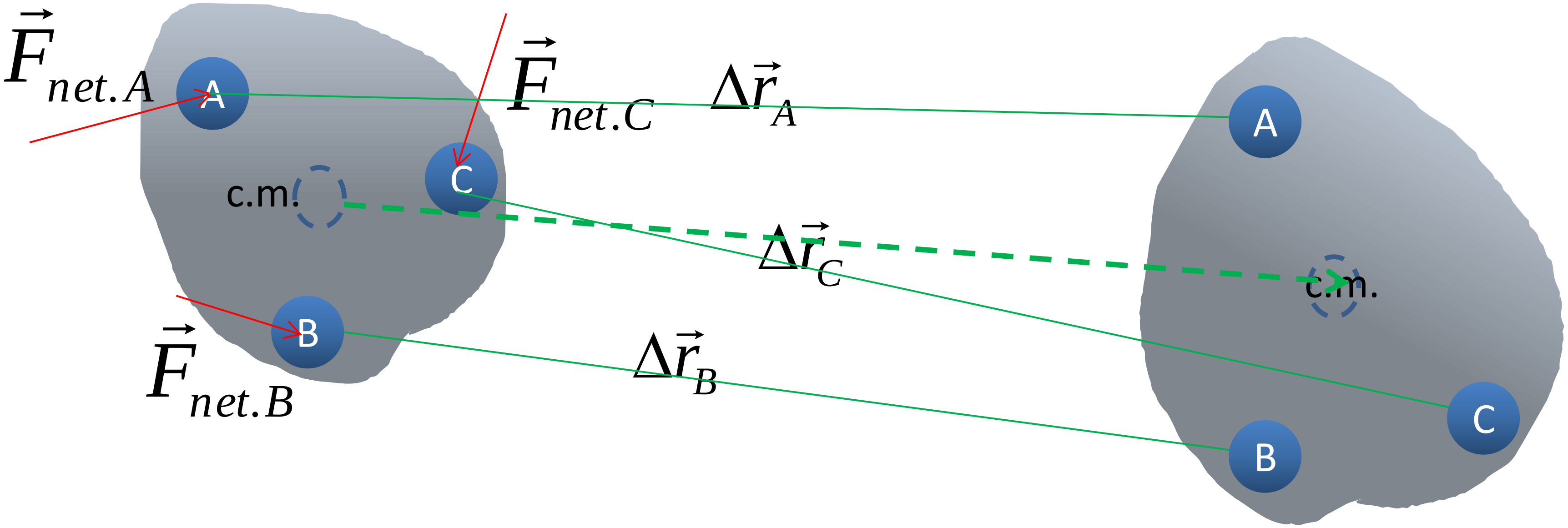
$$v_{cm.f} = \sqrt{\frac{2\Delta K_{trans}}{m_{system}}} = \sqrt{\frac{2(0.035J)}{(2*0.1kg)}} = 0.59\, m/s$$

Work and Translational Kinetic Energy

$$W_{net} = \Delta\left(\tfrac{1}{2} M v_{cm}^2\right) + \Delta E_{\text{internal}} \quad \text{and} \quad "W_{cm}" = \int \vec{F}_{net} \cdot d\vec{r}_{cm} = \Delta\left(\tfrac{1}{2} M v_{cm}^2\right)$$

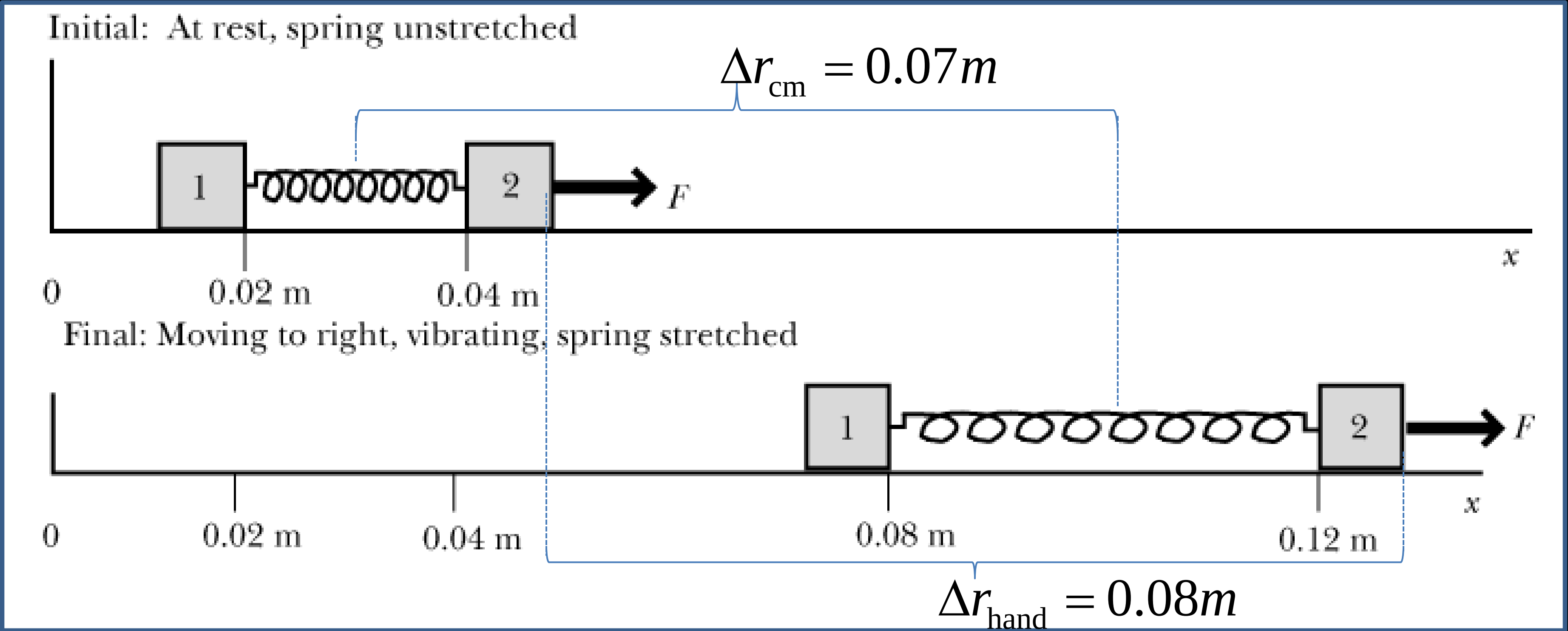
so

$$W_{net} = "W_{cm}" + \Delta E_{\text{internal}} \quad \text{or} \quad W_{net} - "W_{cm}" = \Delta E_{\text{internal}}$$



If we can independently calculate the net work and the work of translating the center of mass, the difference is change in internal energy.

If both blocks have the same mass, by how much did the internal (vibrational kinetic + spring potential) change?



a) 0 J b) 0.005 J c) 0.035 J d) 0.040 J e) 0.075 J

$$\Delta E_{system} = \Delta K_{trans} + \Delta E_{internal}$$

$$\Delta E_{system} = W_{net}$$

$$\Delta E_{system} = \int \vec{F}_{hand} \cdot d\vec{r}_{hand}$$

$$\Delta E_{system} = F_{hand} \Delta r_{hand}$$

$$\Delta E_{system} = (0.5N)(0.08m) = 0.04Nm$$

$$\Delta K_{trans} = \int \vec{F}_{net} \cdot d\vec{r}_{cm}$$

$$\Delta K_{trans} = F_{hand} \Delta r_{cm}$$

$$\Delta K_{trans} = (0.5N)(0.07m) = 0.035Nm$$

Work and Translational Kinetic Energy

Example

$$W_{net} = \Delta E_{\text{system}}$$

$$\sum_i \left(\int \vec{F}_{net \to i} \cdot d\vec{r}_i \right) = \Delta K_{translational} + \Delta E_{\text{internal}}$$

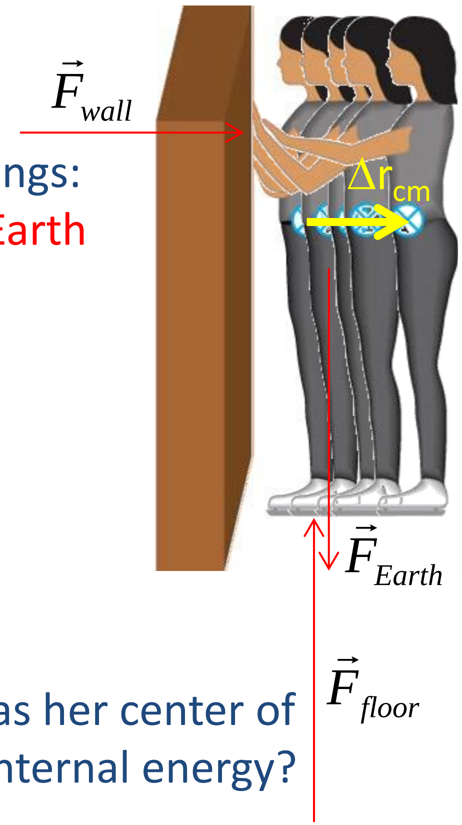
$$0 = \int \vec{F}_{wall} \cdot d\vec{r}_{hand} = \Delta K_{translational} + \Delta E_{\text{internal}}$$

Stationary on wall
While force applied

$$\vec{F}_{net.ext} = \vec{F}_{wall} + \vec{F}_{floor} + \vec{F}_{Earth}$$

System: skater

Active surroundings:
wall, floor, Earth



$$-\Delta K_{translational} = \Delta E_{\text{internal}}$$

$$-\int \vec{F}_{net} \cdot d\vec{r}_{cm} = \Delta E_{\text{internal}}$$

$$-\int \vec{F}_{wall} \cdot d\vec{r}_{cm} = \Delta E_{\text{internal}}$$

Say an average force of 10 N applied as her center of mass moves 0.3 m. What change in internal energy?

$$-10N \cdot 0.3m = \Delta E_{\text{internal}}$$

$$-3J = \Delta E_{\text{internal}} = -\Delta K_{translational}$$

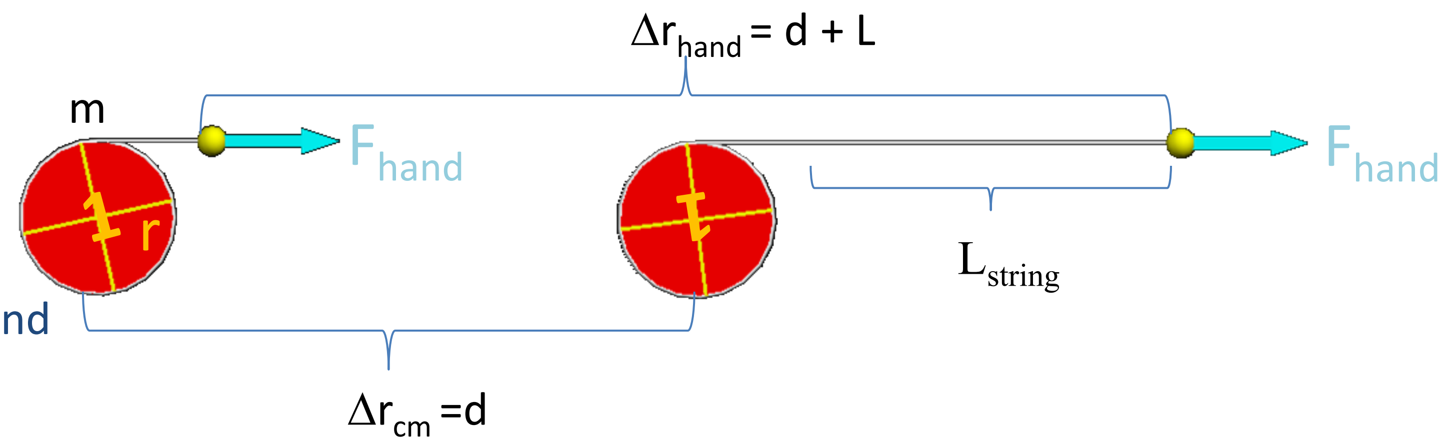
If she was initially at rest, and her mass is 50 kg, with what speed does she (her c.m.) leave the wall?

$$-\Delta E_{\text{int}} = \tfrac{1}{2} m \left(v_{cm.f}^2 - v_{cm.i}^2 \right)$$

$$\sqrt{\frac{2(-\Delta E_{\text{int}})}{m}} = v_{cm.f}$$

$$\sqrt{\frac{6J}{50kg}} = v_{cm.f} = 0.35m/s$$

Example: Pulling spinning puck



System: Puck
Active surroundings: Hand

If it started from rest, how fast was it going at the end?
What was its rotational kinetic energy?
If a uniform disc of radius r, what was its angular speed?

$$\int \vec{F}_{hand} \cdot d\vec{r}_{cm} = \Delta K_{trans}$$

$$F_{hand} d = \Delta K_{trans}$$

$$F_{hand} d = \tfrac{1}{2} m\left(v_{cm.f}^2 - v_{cm.i}^2\right)$$

$$v_{cm.f} = \sqrt{\frac{2F_{hand} d}{m}}$$

$$W_{net} = \Delta E_{\text{puck}}$$

$$\int \vec{F}_{hand} \cdot d\vec{r}_{hand} = \Delta K_{translational} + \Delta E_{\text{internal}}$$

$$F_{hand}\left(d + L\right) = F_{hand} d + \Delta E_{irot}$$

$$F_{hand} L = \Delta E_{irot}$$

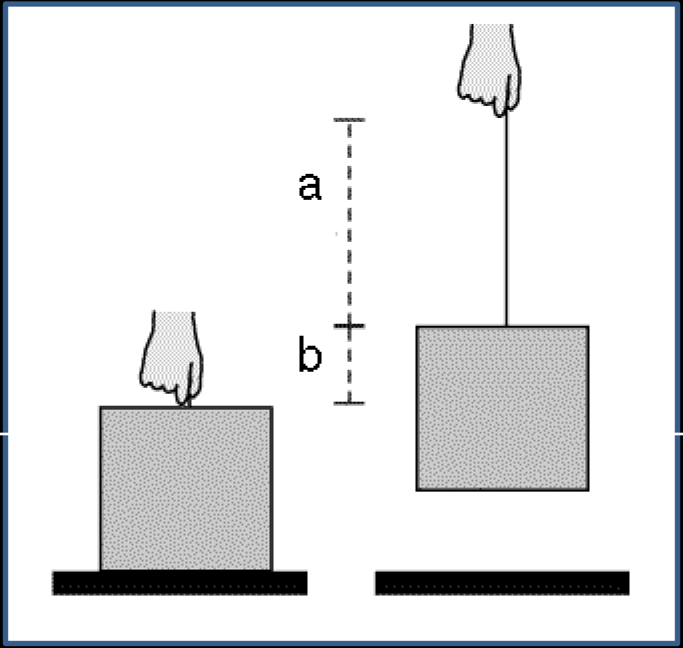
$$I_{disc} = \tfrac{1}{2} m r^2$$

$$F_{hand} L = \tfrac{1}{2} I_{disc}\left(\omega_f^2 - \omega_i^2\right)$$

$$\omega_f = \sqrt{\frac{2F_{hand} L}{I_{disc}}} = \sqrt{\frac{4F_{hand} L}{m r^2}}$$

07_twodiscs.py

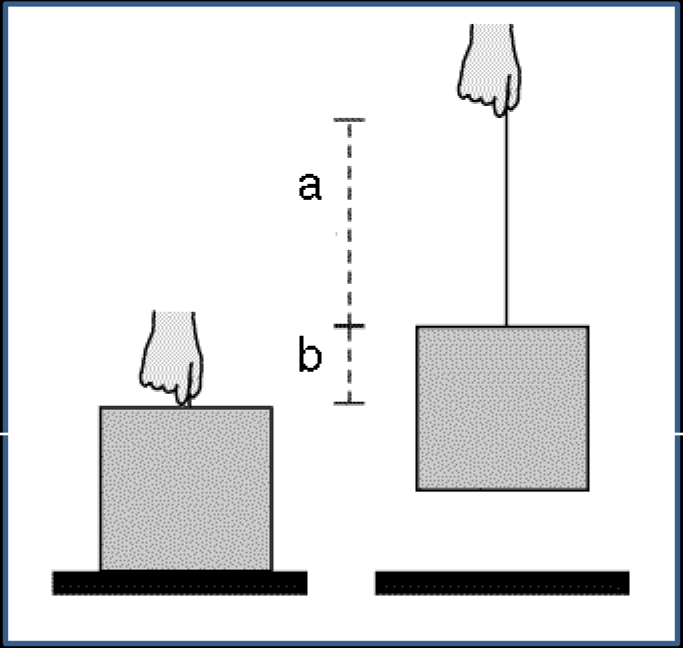
You pull up with constant force F



What is the change in translational kinetic energy of the box?

1) F*b – mg*b
2) F*a – mg*b
3) F*(a+b) – mg*(b)
4) F*(a+b) – mg*(a+b)

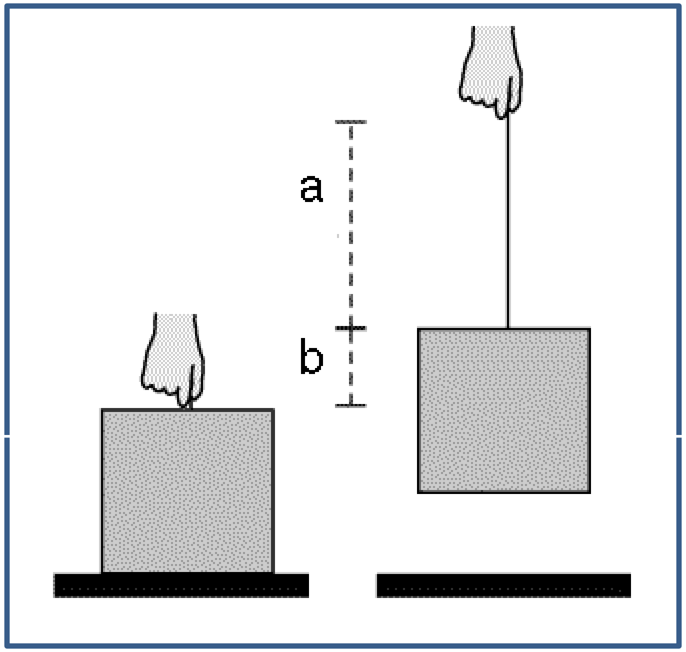
You pull up with constant force F



What was the net work done on the box?

1) F*b – mg*b
2) F*a – mg*b
3) F*(a+b) – mg*(b)
4) F*(a+b) – mg*(a+b)

You pull up with constant force F



So the change in internal energy is

$$W_{net} - \Delta K_{\text{translational}} = \Delta E_{\text{internal}}$$

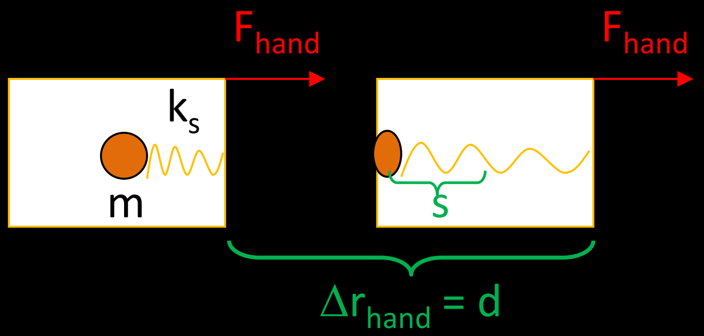
$$\left(F\left(b+a\right)-mgb\right)-\left(Fb-mgb\right)=\Delta E_{\text{internal}}$$

$$Fa = \Delta E_{\text{internal}}$$

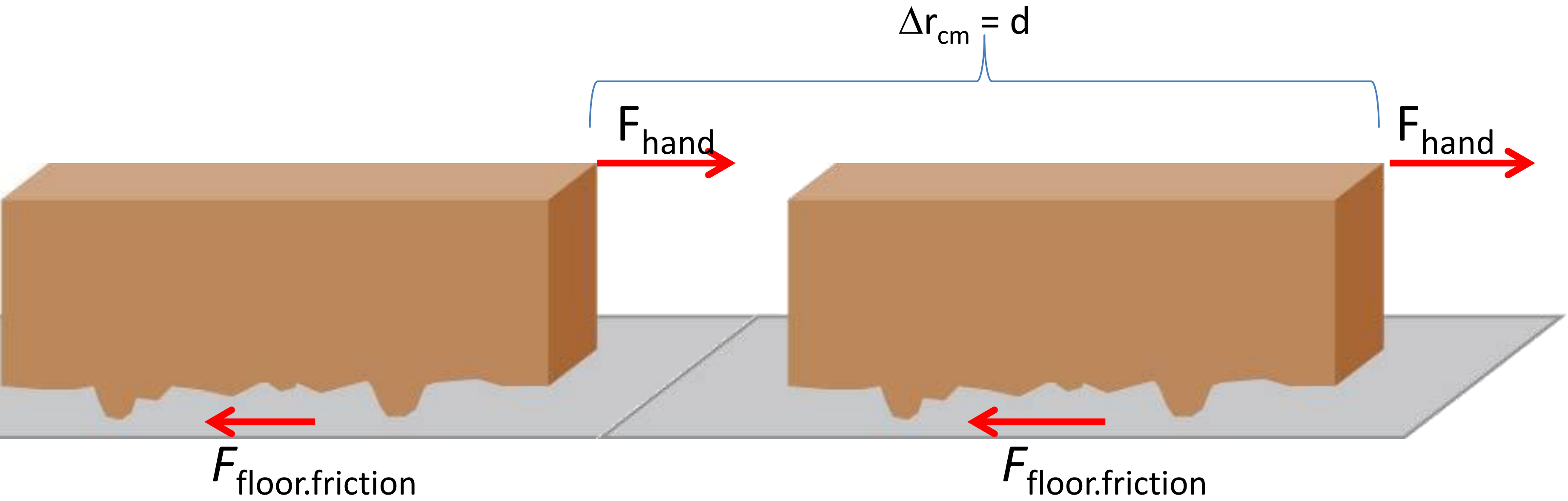
Exercise: You have a box containing a squishy mass on a spring (initially at its equilibrium length); when you pull it sideways, the spring extends until the mass squashes against the far wall of the box. In terms of the labeled properties, if the ball is much more massive than the box or spring,

A) What's the center of mass's speed?

B) What's the increase in the ball's internal energy?



Friction



Center of Mass Motion

$$\int \vec{F}_{net} \cdot d\vec{r}_{cm} = \Delta K_{trans}$$

$$\left(F_{hand} - F_{fl.\,friction}\right)d = \Delta\left(\tfrac{1}{2} M v_{cm}^2\right)$$

If forces are equal, no change in kinetic – constant speed.

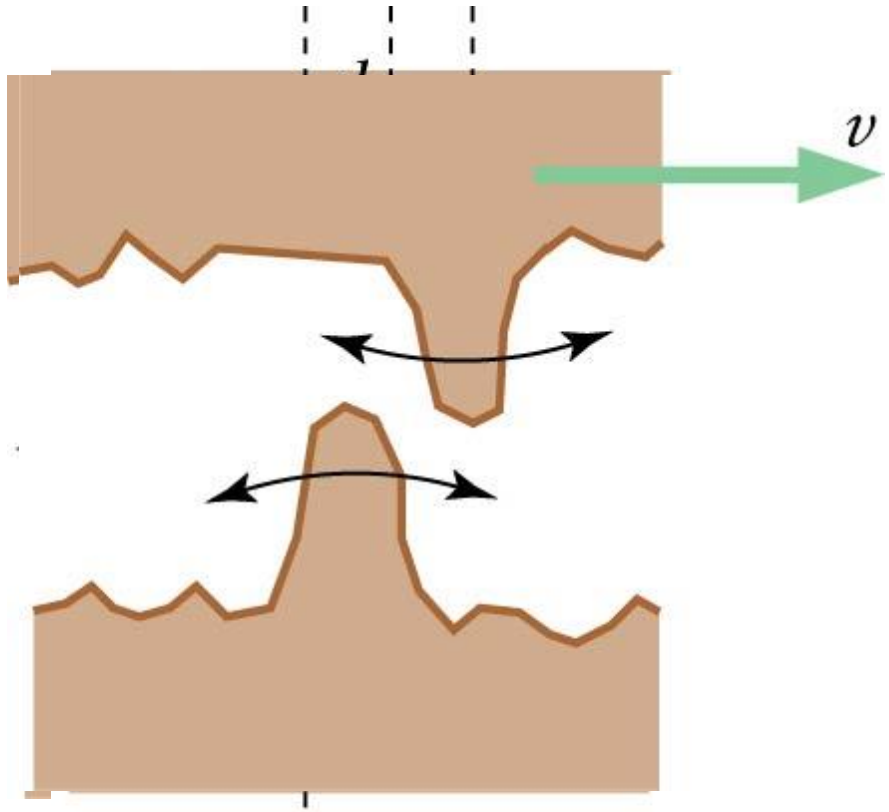
Total Work and Energy

$$W_{net} = \Delta E_{\text{system}}$$

Over what distance *is* friction applied?

$$F_{hand} d + \int \vec{F}_{fl.\,friction} \cdot d\vec{r}_{friction} = \sum_i \left(\int \vec{F}_i \cdot d\vec{r}_i\right) = \Delta K_{\text{trans}} + \Delta E_{\text{int}}$$

Friction



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