Fri.	6.5-.7 (.22) Rest Mass,Work by Changing Forces Columbia Rep 3pm, here	RE 6.b (*last day to drop*)
Wed.	6.8-.9(.18, .19) Introducing Potential Energy …	RE 6.c
Tues.		HW6: Ch 6 Pr's 58,59, 99(a-c), 105(a-c)

motion is neither created nor destroyed, but transferred via interactions.

Energy *Work*

$$\Delta E = W$$

$$\gamma_f mc^2 - \gamma_i mc^2 = \sum_{all}\left(\int_i^f \vec{F}_{\to sys} \cdot d\vec{r}_{sys}\right)$$

$$\gamma = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$

$$E \equiv \gamma mc^2$$ [redacted] $$E_{rest} \equiv mc^2$$

$$K \equiv E - E_{rest} = (\gamma - 1)mc^2 \approx \tfrac{1}{2}mv^2$$

$$K = (\gamma - 1)mc^2$$ $$K \approx \tfrac{1}{2}mv^2$$

A ball whose mass is 2 kg travels at a velocity of < 0, –3, 4> m/s. What is the kinetic energy of the ball?	**1) < 0, –6, 8 > J** **2) < 0, –3, 4 > J** **3) 2 J** **4) 10 J** **5) 25 J**

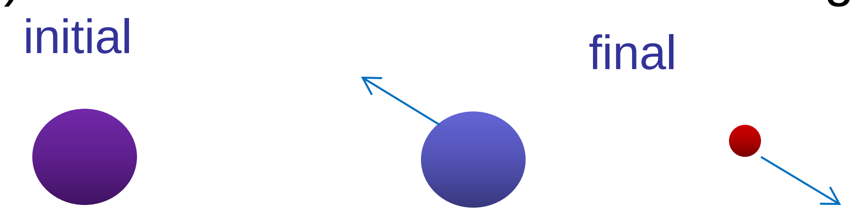
$$K = (\gamma - 1)mc^2$$

$$K \approx \tfrac{1}{2}mv^2$$

Consider an electron (mass 9e-31 kg) moving with speed v = 0.9c. Its rest energy is 0.81e-13 J, and its (total) particle energy is 1.86e-13 J. What is its kinetic energy?	1) 7.3e-31 J 2) 3.28e-14 J 3) 8.1e-14 J 4) 1.05e-13 J 5) 1.86e-13 J

Rest Energy and Identity

Example: A stationary nucleus whose mass is 3.499612×10^{-25} kg undergoes spontaneous "alpha" decay. The original nucleus spits out a He-4 nucleus (2 neutrons & 2 protons) of mass 6.640678×10^{-27}kg and the remaining nucleus has a mass of 3.433132×10^{-25}kg. When the particles are far apart (so the electric repulsion is negligible) what is the combined kinetic energy?



$$\text{parent nucleus} \rightarrow \text{daughter nucleus} + \alpha \text{ particle}$$

System: these particles

Active surroundings: none

$$\Delta E = W = 0$$

$$\Delta E_{rest} + \Delta K = 0$$

or

$$\Delta K = -\Delta E_{rest}$$

In the initial *mass* is the *potential* for the final *motion*…

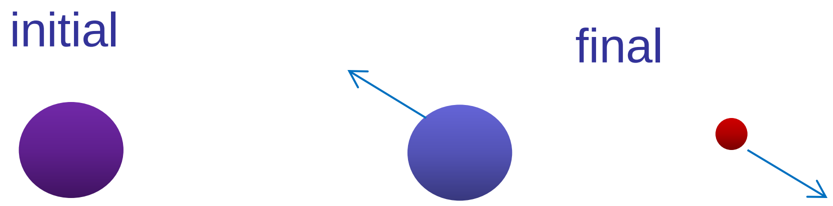
$$K_f - K_i = -\left(E_{rest.f} - E_{rest.i}\right)$$

$$K_f = m_p c^2 - \left(m_d + m_\alpha\right)c^2$$

$$K_f = \left(\left(349.9612 - \left(343.3132 + 6.640678\right)\right)\times10^{-27}\,kg\right)c^2$$

$$K_f = \left(7.322\times10^{-30}\,kg\right)c^2 = 6.59\times10^{-13}\,J$$

Chemistry-Scaled Energy Units



$$\text{parent nucleus} \rightarrow \text{daughter nucleus} + \alpha \text{ particle}$$

$$K_f = \left(7.322\times10^{-30}\,kg\right)c^2 = 6.59\times10^{-13}\,J$$

All chemical interactions are fundamentally *electric* interactions, so involve electric force and scale with electron charge.

$$1Joul = 1Joul\,\frac{1e}{1.6\times10^{-19}\,Coulombs} = 6.25\times10^{18}\,e\,\frac{J}{C} = 6.25\times10^{18}\,eV$$

$$Volt \equiv \frac{Joul}{Coulombs}$$

Chemical reactions typically involve 10 meV to 10 eV of energy per molecule

$$K_f = 6.59\times10^{-13}\,J\cdot\left(\frac{6.25\times10^{18}\,eV}{1J}\right) = 4.12\times10^{6}\,eV = 4.12\,MeV$$

A nuclear reaction involves *millions* of times more energy than does Chemical reaction!

Systematic Approach to Energy Problems

1) Specify a system (the object or object's you're interested in)
2) Specify members of the surrounding that interact with the system
3) Specify the initial state
4) Specify the final state
5) Write out the Energy Principle for this system
6) Use the given information to evaluate all terms you can
7) Solve for the target unknown quantity
8) Check units and consistency of sign.

Work – Energy Relation

You drop a metal ball from 1 m up. How fast is it going just before it hits the ground?

$$\Delta E = W$$

$$W \approx W_{Ball \leftarrow Earth}$$

$$W_{Ball \leftarrow Earth} = \int_i^f \vec{F}_{Ball \leftarrow Earth} \cdot d\vec{r}_{Ball}$$

Constant force, so

$$W_{Ball \leftarrow Earth} = \vec{F}_{Ball \leftarrow Earth} \cdot \Delta\vec{r}_{Ball}$$

$$W_{Ball \leftarrow Earth} = (mg)\hat{y} \cdot (\Delta y)\hat{y}$$

$$W_{Ball \leftarrow Earth} = mg\Delta y$$

System= ball

Active members of environment = Earth (neglecting air's resistance)

initial

$$\Delta\vec{r}_{ball} = (\Delta y)\hat{y}$$

$$\Delta y = 1\text{m}$$

$$\vec{F}_{Ball \leftarrow Earth} = mg\hat{y}$$

final

$$\left|\vec{v}_f\right| = ?$$

$\hat{y}$

Not changing

$$\Delta E_{rest} + \Delta K = \Delta E$$

$$K_f - K_i = \Delta E$$

Pretty sure *v*<<*c*, so $K \approx \frac{1}{2}mv^2$

$$\tfrac{1}{2}mv_f^2 = \Delta E \approx W_{Ball \leftarrow Earth} = mg\Delta y$$

$$\tfrac{1}{2}mv_f^2 \approx mg\Delta y$$

$$v_f \approx \sqrt{2g\Delta y} = \sqrt{2\left(9.8\,{}^{m}/_{s^2}\right)(1m)} = 4.4\,{}^{m}/_{s}$$

If we throw the ball down at 5m/s, will have greater, less, or the same speed when it lands?	**1) greater** **2) less** **3) The same**

Work – Energy Relation

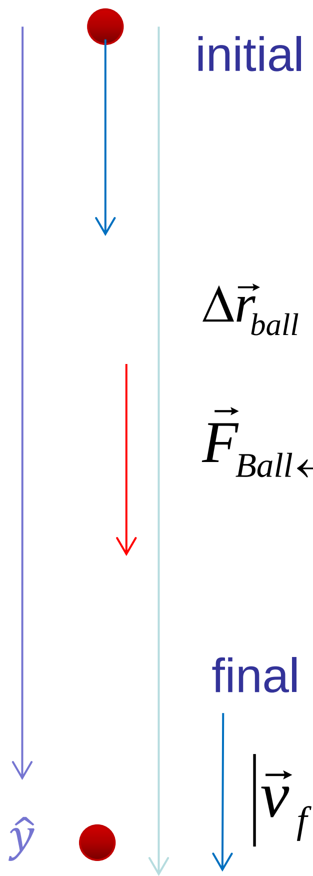
Slight variation: You *throw* a metal ball straight down at 5 m/s from 1 m up. How fast is it going just before it hits the ground?

What changes in our solution?

System= ball

Active members of environment = Earth (neglecting air's resistance)

$\vec{v}_i = 5\,{}^{m}\!/\!{}_{s}\,\hat{y}$



$|\vec{v}_f| = ?$

$\Delta\vec{r}_{ball} = (\Delta y)\hat{y}$

$\Delta y = 1\text{m}$

$\vec{F}_{Ball\leftarrow Earth} = mg\hat{y}$

$$\Delta E = W$$

$$W \approx W_{Ball\leftarrow Earth}$$

$$W_{Ball\leftarrow Earth} = \int_i^f \vec{F}_{Ball\leftarrow Earth}\cdot d\vec{r}_{Ball}$$

Constant force, so

$$W_{Ball\leftarrow Earth} = \vec{F}_{Ball\leftarrow Earth}\cdot\Delta\vec{r}_{Ball}$$

$$W_{Ball\leftarrow Earth} = (mg)\hat{y}\cdot(\Delta y)\hat{y}$$

$$W_{Ball\leftarrow Earth} = mg\Delta y$$

Not changing

$$\Delta E_{rest} + \Delta K = \Delta E$$

$$K_f - K_i = \Delta E$$

Pretty sure *v*<<*c*, so $K \approx \frac{1}{2}mv^2$

$$\frac{1}{2}m\left(v_f^2 - v_i^2\right) = \Delta E \approx W_{Ball\leftarrow Earth} = mg\Delta y$$

$$\frac{1}{2}mv_f^2 \approx mg\Delta y + \frac{1}{2}mv_i^2$$

$$v_f \approx \sqrt{2g\Delta y + v_i^2} = 6.7\,{}^{m}\!/\!{}_{s}$$

If we throw the ball up at 5m/s, will have greater, less, or the same speed when it lands compared with what it had in when thrown 5m/s down?	1) greater 2) less 3) The same

Work – Energy Relation

Another Slight variation: You *throw* a metal ball straight *up* at $5\,{}^{m}/_{s}$ from 1 m up. How fast is it going just before it hits the ground? **What changes now?**

$$\Delta E = W$$

$$W \approx W_{Ball \leftarrow Earth}$$

$$W_{Ball \leftarrow Earth} = \int_i^f \vec{F}_{Ball \leftarrow Earth} \cdot d\vec{r}_{Ball}$$

Constant force, so

$$W_{Ball \leftarrow Earth} = \vec{F}_{Ball \leftarrow Earth} \cdot \Delta\vec{r}_{Ball}$$

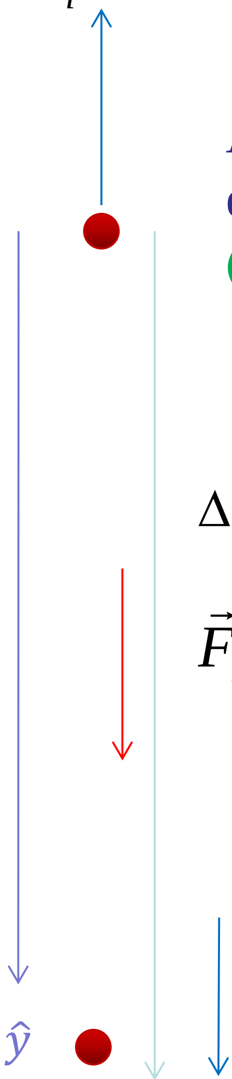
$$W_{Ball \leftarrow Earth} = (mg)\hat{y} \cdot (\Delta y)\hat{y}$$

$$W_{Ball \leftarrow Earth} = mg\Delta y$$

$$\vec{v}_i = -5\,{}^{m}\!/_{s}\,\hat{y}$$

System= ball

Active members of environment = Earth (neglecting air's resistance)



$$\Delta\vec{r}_{ball} = (\Delta y)\hat{y}$$

$$\Delta y = 1\text{m}$$

$$\vec{F}_{Ball \leftarrow Earth} = mg\hat{y}$$

$$\left|\vec{v}_f\right| = ?$$

Not changing

$$\Delta E_{rest} + \Delta K = \Delta E$$

$$K_f - K_i = \Delta E$$

Pretty sure *v*<<*c*, so $K \approx \frac{1}{2}mv^2$

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$$\tfrac{1}{2}mv_f^2 \approx mg\Delta y + \tfrac{1}{2}mv_i^2$$

$$v_f \approx \sqrt{2g\Delta y + v_i^2} = 6.7\,{}^{m}\!/_{s}$$

Nothing Changes!

Work – Energy Relation

Example: An electron (mass 9e-31 kg) is traveling at a speed of 0.95*c* in an electron accelerator. Over what distance would an electric force of 1.6e^{-13} N have to be applied to accelerate it to 0.99c?

$\vec{v}_i = (0.95c)\hat{y}$ System= electron

Active members of environment = Accelerator

initial

$\Delta \vec{r}_e = (?)\hat{y}$

$\vec{F}_{e\leftarrow accelerator} = (1.6\times10^{-13}N)\hat{y}$

final

$\vec{v}_f = (0.99c)\hat{y}$

$\hat{y}$

$$\Delta E = W$$

$$\left(\gamma_f mc^2 - \gamma_i mc^2\right) = \int_i^f \vec{F}\cdot d\vec{r}$$

$$\left(\gamma_f - \gamma_i\right)mc^2 = F\Delta y$$

where

$$\gamma = \frac{1}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$$

$$\left(\gamma_f - \gamma_i\right)\frac{mc^2}{F} = \Delta y$$

$$\Delta y = \left(\frac{1}{\sqrt{1-(0.99)^2}} - \frac{1}{\sqrt{1-(0.95)^2}}\right)\frac{(9\times10^{-31}kg)(3\times10^8 m/s)^2}{1.6\times10^{-13}N}$$

$$\Delta y = 37m$$

Let's say the Wizard of Oz's balloon has a total mass of 1000 kg (including the Wizard in the basket) and has most of its volume in the balloon which has a radiu of 10 m. If the Scarecrow, whose mass is 50 kg (he is only made of straw after a grabs a hold, when it starts lifting off, how fast will it be going when it gets 3 m up at which point the Scarecrow lets go and drops?

Recall that air has a density of 1.3×10^{-3} g / cm^3.

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Recall that air has a density of 1.3×10^{-3} g / cm^3.

Now you try. How much work did the balloon do on the scarecrow during his brief ride?

System

Active Surroundings

Initial State

Final State

Work-Energy Relation

Algebra

Numbers

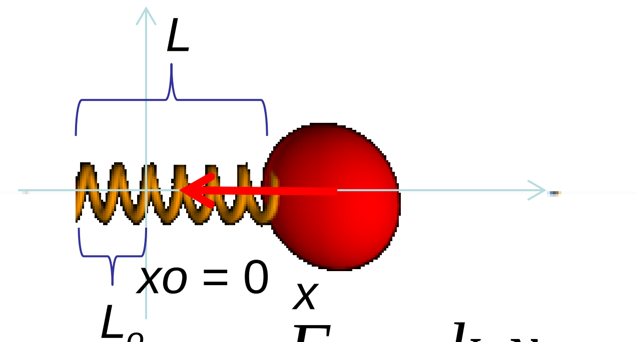
Check units and sign

Work by Changing Force

$$W = \vec{F}_1 \cdot \Delta\vec{r}_1 + \vec{F}_2 \cdot \Delta\vec{r}_2 + \vec{F}_3 \cdot \Delta\vec{r}_3 + \ldots.\vec{F}_{20} \cdot \Delta\vec{r}_{20} = \sum_{i=1}^{20} \vec{F} \cdot \Delta\vec{r}$$

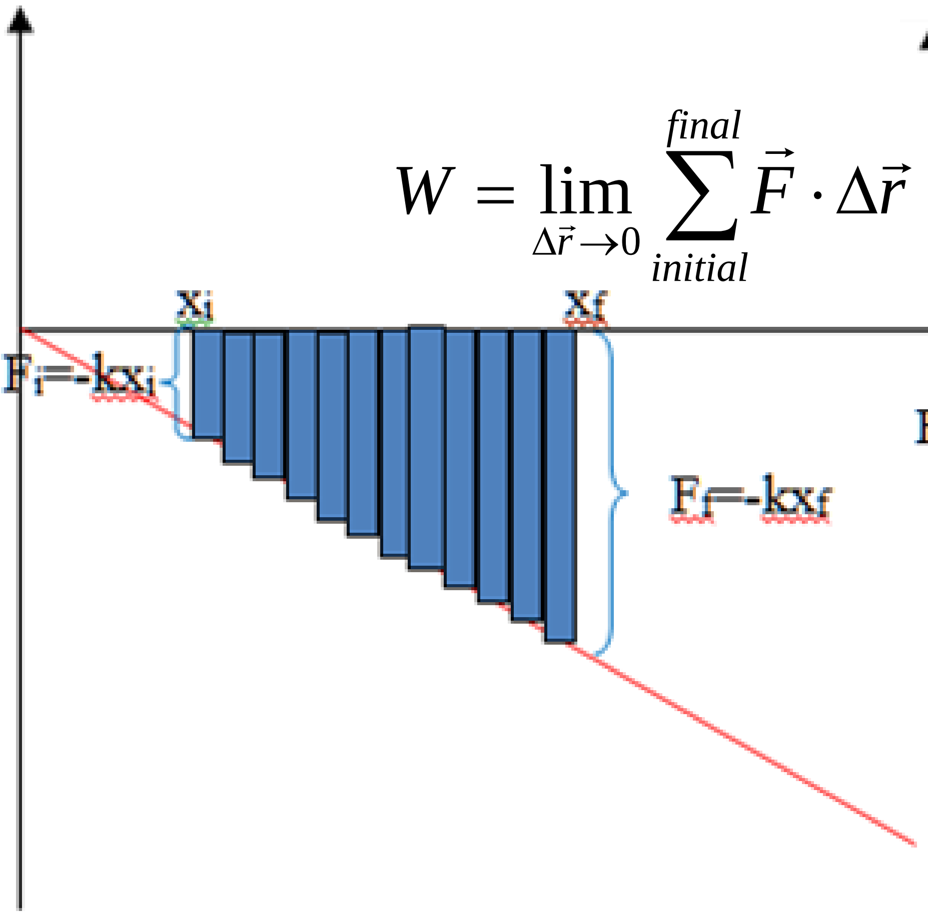
$$W = \lim_{\Delta\vec{r} \to 0} \sum_{initial}^{final} \vec{F} \cdot \Delta\vec{r} = \int_{init}^{fin} \vec{F} \cdot d\vec{r}$$

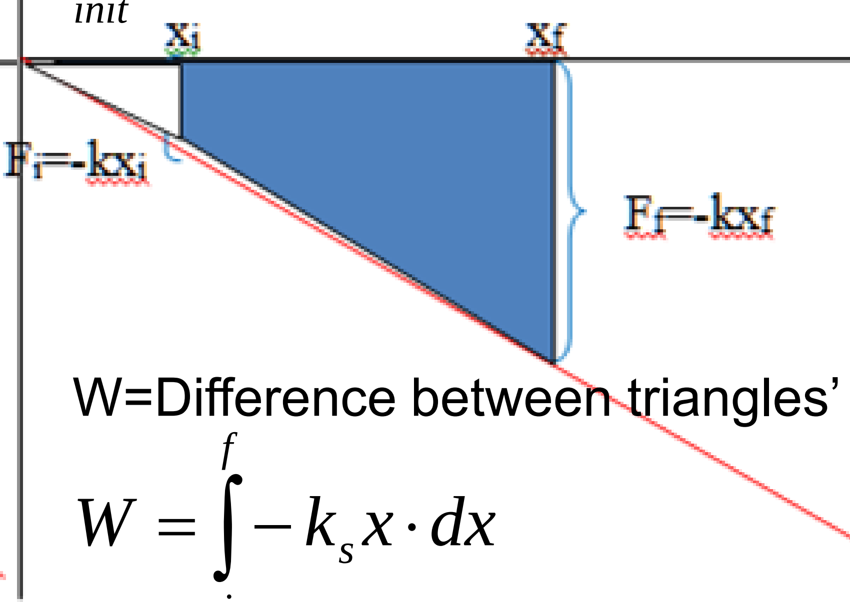
Work by Changing Force
Spring



$$F = -k_s x$$

$$W = \lim_{\Delta\vec{r}\to 0} \sum_{initial}^{final} \vec{F}\cdot\Delta\vec{r} = \int_{init}^{fin} \vec{F}\cdot d\vec{r}$$





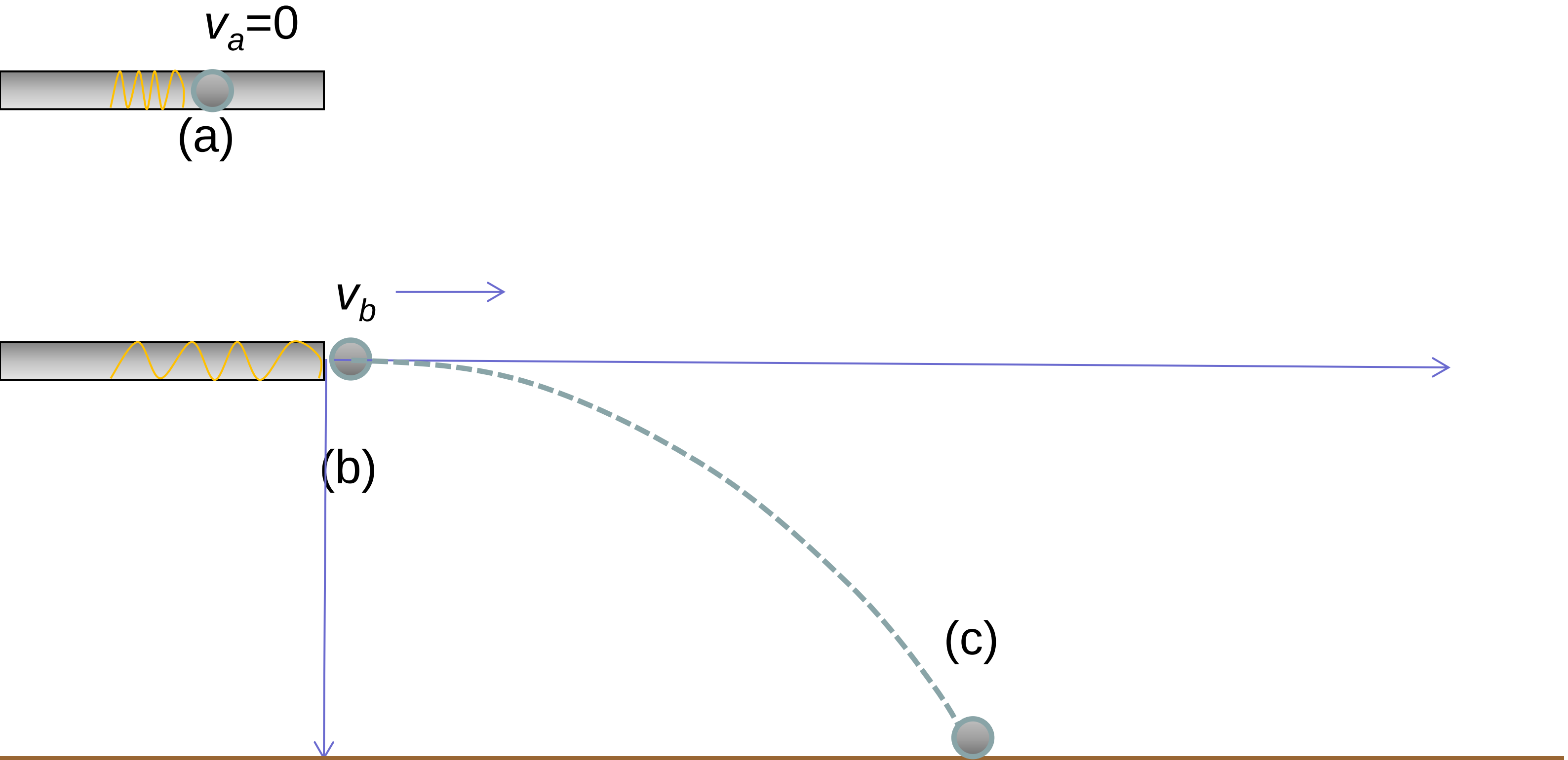
W=Difference between triangles' areas

$$W = \int_i^f -k_s x \cdot dx$$

$$W = -\tfrac{1}{2} k_s x^2 \Big|_i^f$$

$$W = -\tfrac{1}{2} k_s \left(x_f^2 - x_i^2\right)$$

In an up-coming lab, you'll use a spring-loaded gun to fire a metal ball. If we know the ball's mass, the stiffness of the spring and how much it's been stretched, then we should be able to predict where the ball will hit the ground. Say the spring is initially compressed by 0.04m, and when it launches the ball it stretches to a compression of 0.01m; if the ball is 0.05kg and the gun is mounted 0.8m above the ground, then how far over will the ball hit the ground?



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motion is neither created nor destroyed, but transferred via interactions.

Energy → ← *Work*

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[redacted]

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