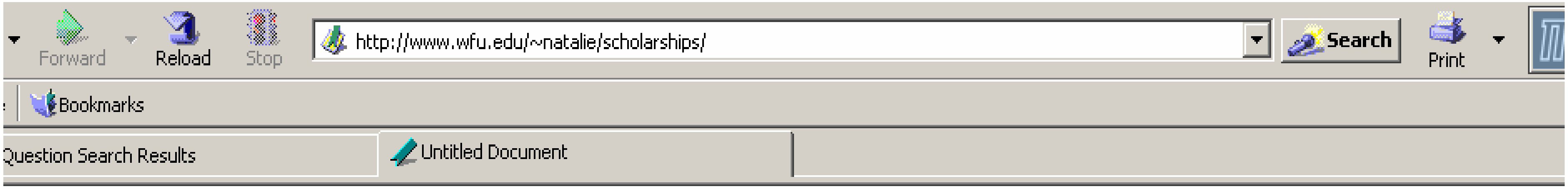
Announcements

1. **Physics colloquium (Professor Brian Matthews) cancelled.**
2. **Scholarship opportunities for undergraduate students**
3. **Schedule -- First exam – Tuesday, Sept. 30th**

   Review Chapters 1-8 – Thursday, Sept. 25th

   Extra practice problems on line

   Extra problem solving sessions???
4. **Some comments on friction and HW 6**
5. **The notion of energy and work**



Scholarship Opportunities for undergraduate students

Wake Forest University Research Fellowships

(for mentored research projects during an academic year or during a summer; available to all WFU students with at least sophomore standing and 3.0 GPA)

Barry M. Goldwater Scholarships

(for tuition and expenses support, available to sophomores or juniors planning careers in mathematics, the natural sciences, or engineering)

Internal deadline: Nov. 14, 2003); Foundation deadline: Feb. 2, 2004

Churchill Scholarships

(for one year of graduate study in engineering, mathematics, and the physical and natural sciences at Churchill College, Cambridge University,
available to graduating seniors) **Internal deadline: Oct. 17, 2003; Foundation deadline: Nov. 21, 2003)**

Surface friction force models

- Static friction

$$\boldsymbol{f} = -F_{applied} \quad \text{if } |\boldsymbol{f}| < \mu_s N$$

- Kinetic friction

$$|\boldsymbol{f}| = \mu_s N$$

4. HRW6 6.P.016. [56520] A 2.5 kg block is pushed along a horizontal floor by a force F of magnitude 20 N at an angle $\theta = 30°$ with the horizontal (Fig. 6-26). The coefficient of kinetic friction between the block and floor is 0.25.

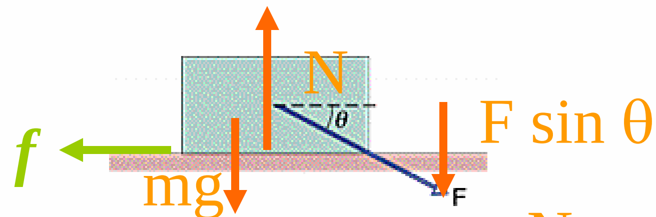


Figure 6-26

$$N - mg - F\sin\theta = 0$$

(a) Calculate the magnitude of the frictional force on the block from the floor.

[0.1176471] ______ N

$$f = \mu_k N$$

(b) Calculate the magnitude of the acceleration of the block.

[0.1176471] ______ m/s^2

$$F\cos\theta - f = ma$$

A slide loving pig slides down a 24° incline (Fig. 6-24) in twice the time it would take to slide down a frictionless 24° incline. What is the coefficient of kinetic friction between the pig and the slide?

Figure 6-24

$$\text{without friction}: \; mg\sin\theta = ma \qquad D = \tfrac{1}{2}at^2$$

$$\text{with friction}: \; mg\sin\theta - \mu_k mg\cos\theta = ma_f \qquad D = \tfrac{1}{2}a_f t_f^2$$

$$t_f = 2t \quad \Rightarrow 4a_f = a \quad \Rightarrow 4(g\sin\theta - \mu_k g\cos\theta) = g\sin\theta$$

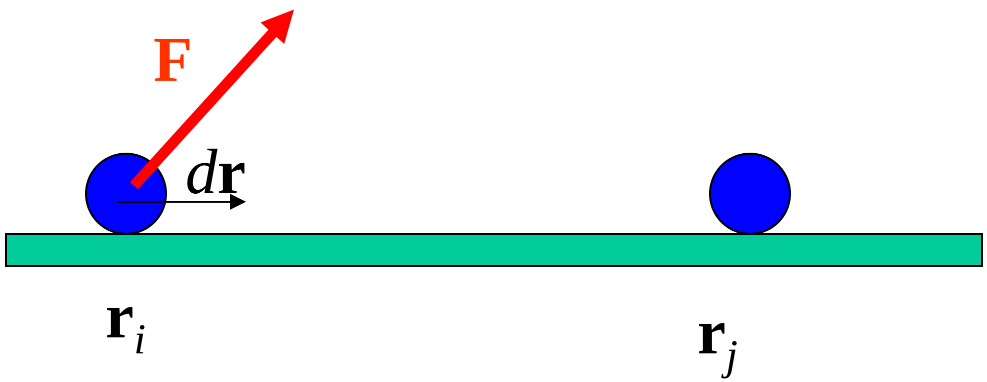
Energy ➔ work, kinetic energy

Force ➔ effects acceleration

A related quantity is **Work**

$$W_{i \to f} = \int_{\mathbf{r}_i}^{\mathbf{r}_f} \mathbf{F} \cdot d\mathbf{r}$$

$\mathbf{A} \cdot B = AB \cos\theta$



Units of work:

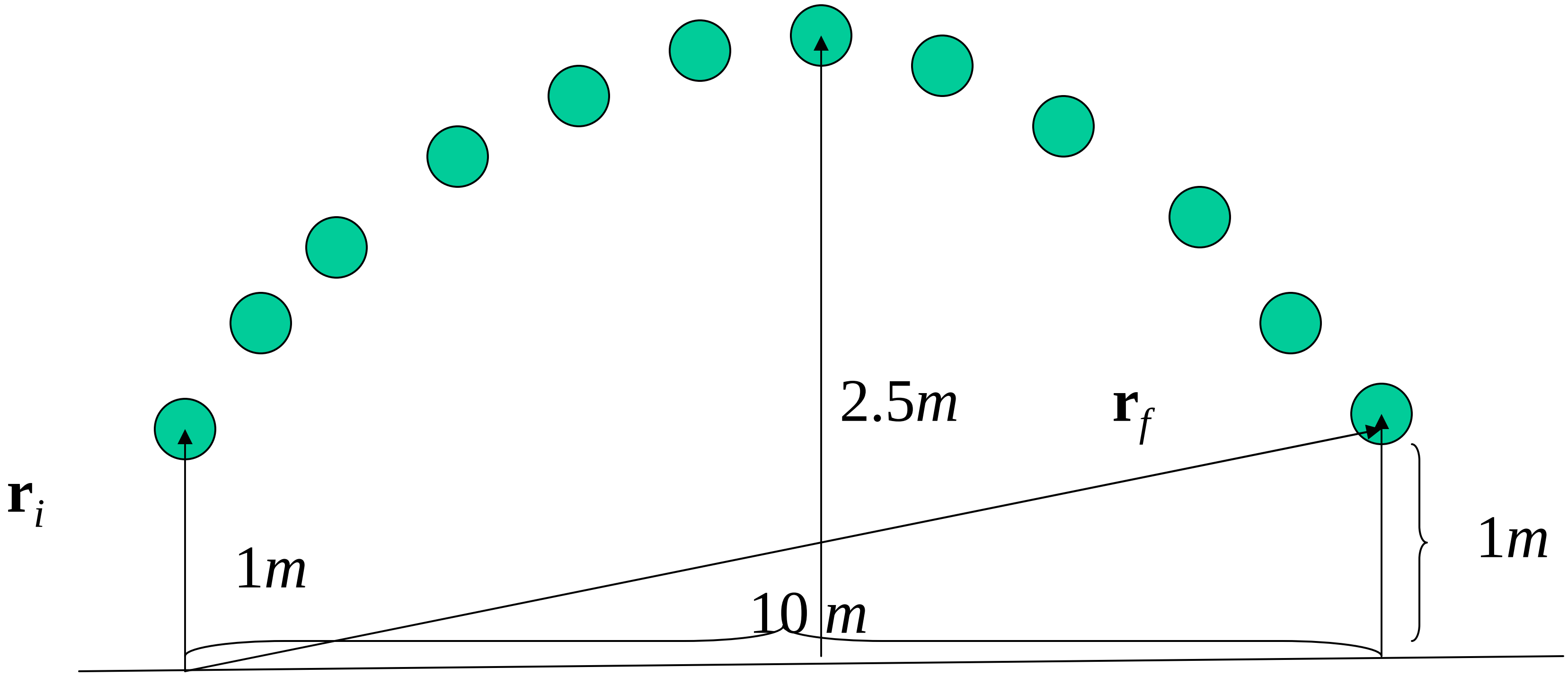
work = force · displacement = (N · m) = (joule)

- Only the component of force in the direction of the displacement contributes to work.
- Work is a *scalar* quantity.
- If the force is not constant, the integral form must be used.
- Work can be defined for a specific force or for a combination of forces

$$W_1 = \int_{\mathbf{r}_i}^{\mathbf{r}_f} \mathbf{F}_1 \cdot d\mathbf{r} \qquad W_2 = \int_{\mathbf{r}_i}^{\mathbf{r}_f} \mathbf{F}_2 \cdot d\mathbf{r} \qquad W_{1+2} = \int_{\mathbf{r}_i}^{\mathbf{r}_f} (\mathbf{F}_1 + \mathbf{F}_2) \cdot d\mathbf{r} = W_1 + W_2$$

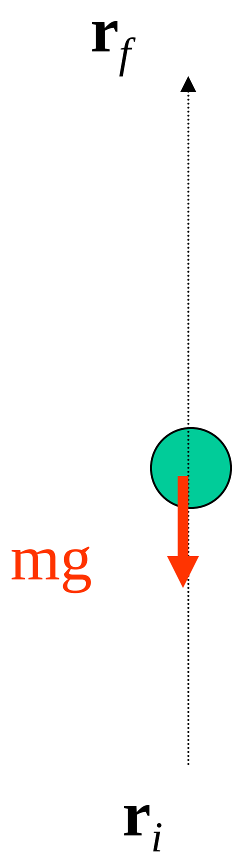
Peer instruction question

A ball with a weight of 5 N follows the trajectory shown. What is the work done by gravity from the initial $\mathbf{r}_i$ to final displacement $\mathbf{r}_f$?



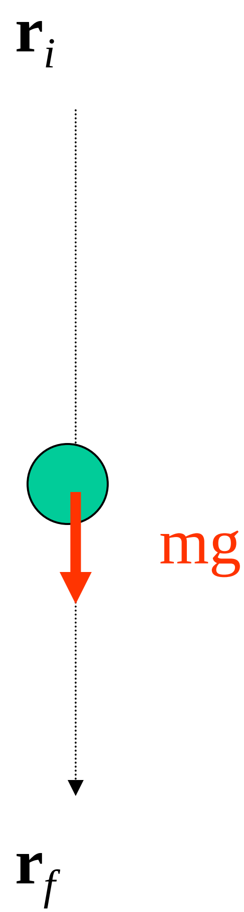
(a) 0 J (b) 7.5 J (c) 12.5 J (d) 50 J

Gravity does negative work:

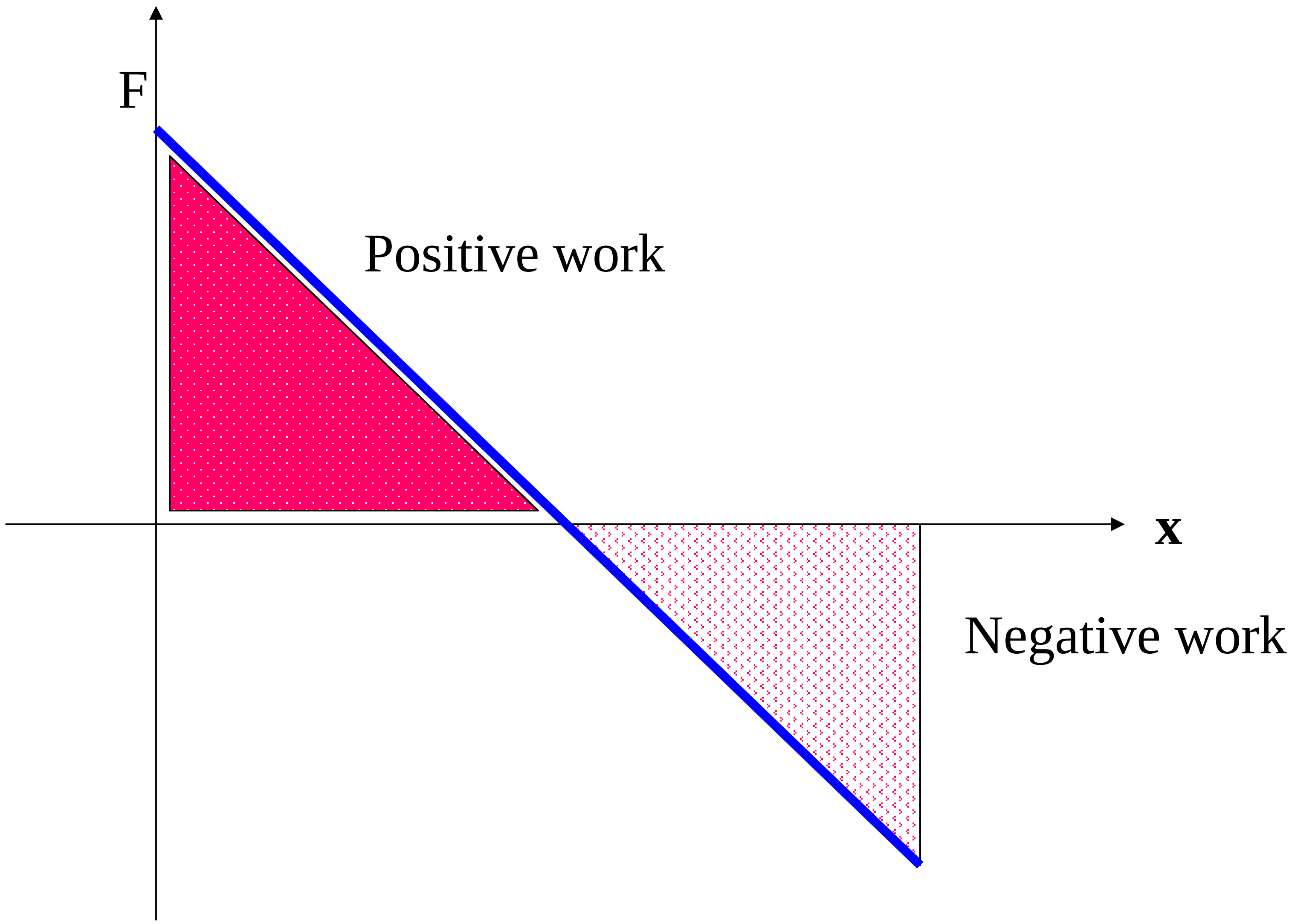


$W = -mg(r_f - r_i) < 0$

Gravity does positive work:



$W = -mg(r_f - r_i) > 0$


F
Positive work
x
Negative work

More examples:

Suppose a rope lifts a weight of 1000N by 0.5m at a constant upward velocity of 2m/s. How much work is done by the rope?

W=500 J

Suppose a rope lifts a weight of 1000N by 0.5m at a constant upward acceleration of $2m/s^2$. How much work is done by the rope?

W=602 J

Why is work a useful concept?

Consider Newton's second law:

$\mathbf{F}_{\text{total}} = \text{m}\,\mathbf{a} \quad \Rightarrow \mathbf{F}_{\text{total}} \cdot \text{d}\mathbf{r} = \text{m}\,\mathbf{a} \cdot \text{d}\mathbf{r}$

$$\int_{\mathbf{r}_i}^{\mathbf{r}_f} \mathbf{F}_{total} \cdot d\mathbf{r} = \int_{\mathbf{r}_i}^{\mathbf{r}_f} m\mathbf{a} \cdot d\mathbf{r} = \int_{\mathbf{r}_i}^{\mathbf{r}_f} m \frac{d\mathbf{v}}{dt} \cdot d\mathbf{r} = \int_{\mathbf{r}_i}^{\mathbf{r}_f} m \frac{d\mathbf{v}}{dt} \cdot \frac{d\mathbf{r}}{dt} dt = \int_{\mathbf{r}_i}^{\mathbf{r}_f} m \frac{d\mathbf{v}}{dt} \cdot \mathbf{v} dt$$

$$W_{\text{total}} = \tfrac{1}{2}\,\text{m}\,\text{v}_f^2 - \tfrac{1}{2}\,\text{m}\,\text{v}_i^2$$

Kinetic energy (joules)

Introduction of the notion of Kinetic energy

Some more details:

Consider Newton's second law:

$\mathbf{F}_{total} = m\,\mathbf{a} \;\rightarrow\; \mathbf{F}_{total} \cdot d\mathbf{r} = m\,\mathbf{a} \cdot d\mathbf{r}$

$$\int_{\mathbf{r}_i}^{\mathbf{r}_f} \mathbf{F}_{total} \cdot d\mathbf{r} = \int_{\mathbf{r}_i}^{\mathbf{r}_f} m\mathbf{a} \cdot d\mathbf{r} = \int_{\mathbf{r}_i}^{\mathbf{r}_f} m\frac{d\mathbf{v}}{dt} \cdot d\mathbf{r} = \int_{t_i}^{t_f} m\frac{d\mathbf{v}}{dt} \cdot \frac{d\mathbf{r}}{dt}\,dt = \int_{t_i}^{t_f} m\frac{d\mathbf{v}}{dt} \cdot \mathbf{v}\,dt$$

$$\int_{t_i}^{t_f} m\frac{d\mathbf{v}}{dt} \cdot \mathbf{v}\,dt = \int_{\mathbf{v}_i}^{\mathbf{v}_f} m\,d\mathbf{v} \cdot \mathbf{v} = \int_{i}^{f} d\left(\frac{1}{2}m\mathbf{v} \cdot \mathbf{v}\right) = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

$\rightarrow W_{total} = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$

Kinetic energy (joules)

Kinetic energy: $K = \frac{1}{2} m v^2$

$$\text{units: } (\text{kg})\,(\text{m/s})^2 = \underbrace{(\text{kg m/s}^2)}_{\text{N}}\ \underbrace{\text{m}}_{\text{m}} = \text{joules}$$

Work – kinetic energy relation:

$$W_{total} = K_f - K_i$$

Online Quiz for Lecture 7
The Notion of Kinetic Energy -- Sept. 18, 2003

Suppose you hit a golf ball having a mass of 0.4 kg with an initial velocity of v_i = 45 m/s and an initial angle of 45 deg. Assume that the ball makes a perfectly parabolic trajectory and lands at the same vertical height as it started.

1. What is the initial kinetic energy of the ball?
   (a) -202.5J (b) 202.5J (c) -405 J (d) 405 J
2. What is the final kinetic energy of the ball just before it reaches the ground?
   (a) -202.5J (b) 202.5J (c) -405 J (d) 405 J
3. What is the kinetic energy of the ball at the highest point of the trajectory?
   (a) -202.5J (b) 202.5J (c) -405 J (d) 405 J

Examples of the work—kinetic energy relation:

Suppose F_{total} = constant= F_0

$W_{total} = K_f - K_i$

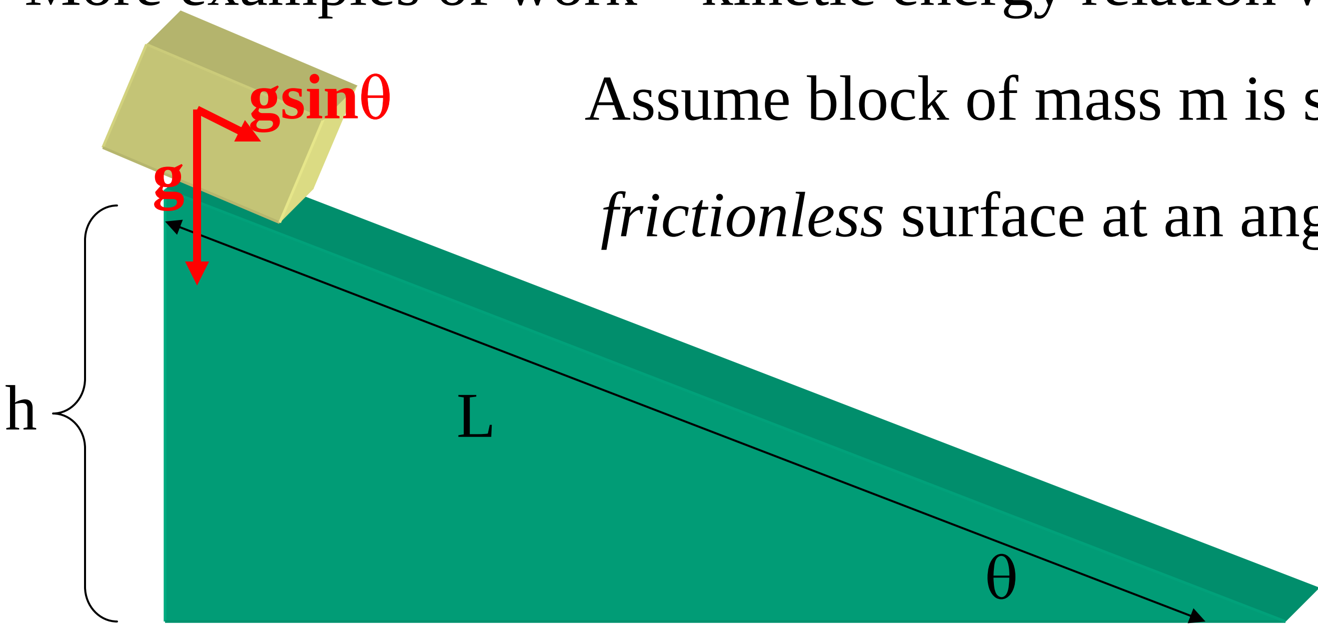
➔ $F_0(x_f - x_i) = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$

In this case, we also know that $F_0 = ma_0$ so that,

$F_0(x_f - x_i) = ma_0\,(x_f - x_i) = \frac{1}{2} m v_f^2 - \frac{1}{2} m v_i^2$

➔ $v_f^2 = v_i^2 + 2a_0\,(x_f - x_i)$

More examples of work—kinetic energy relation without friction:

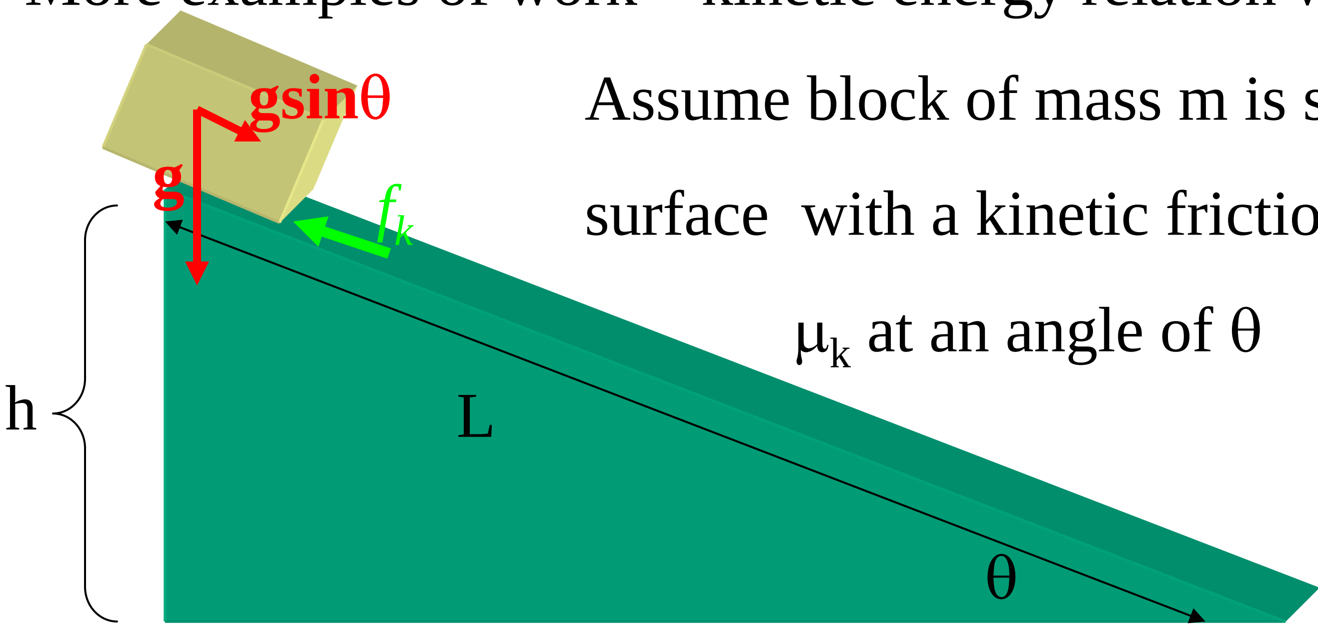


Assume block of mass m is sliding down a *frictionless* surface at an angle of θ

kinematic analysis: $v_f^2 = v_i^2 + 2a_0 (x_f - x_i) = 0 + 2(g \sin\theta)L = 2gh$

energy analysis: $W_{total} = mgh = ½ mv_f^2$

More examples of work—kinetic energy relation with friction:



Assume block of mass m is sliding down a surface with a kinetic friction coefficient of μ_k at an angle of θ

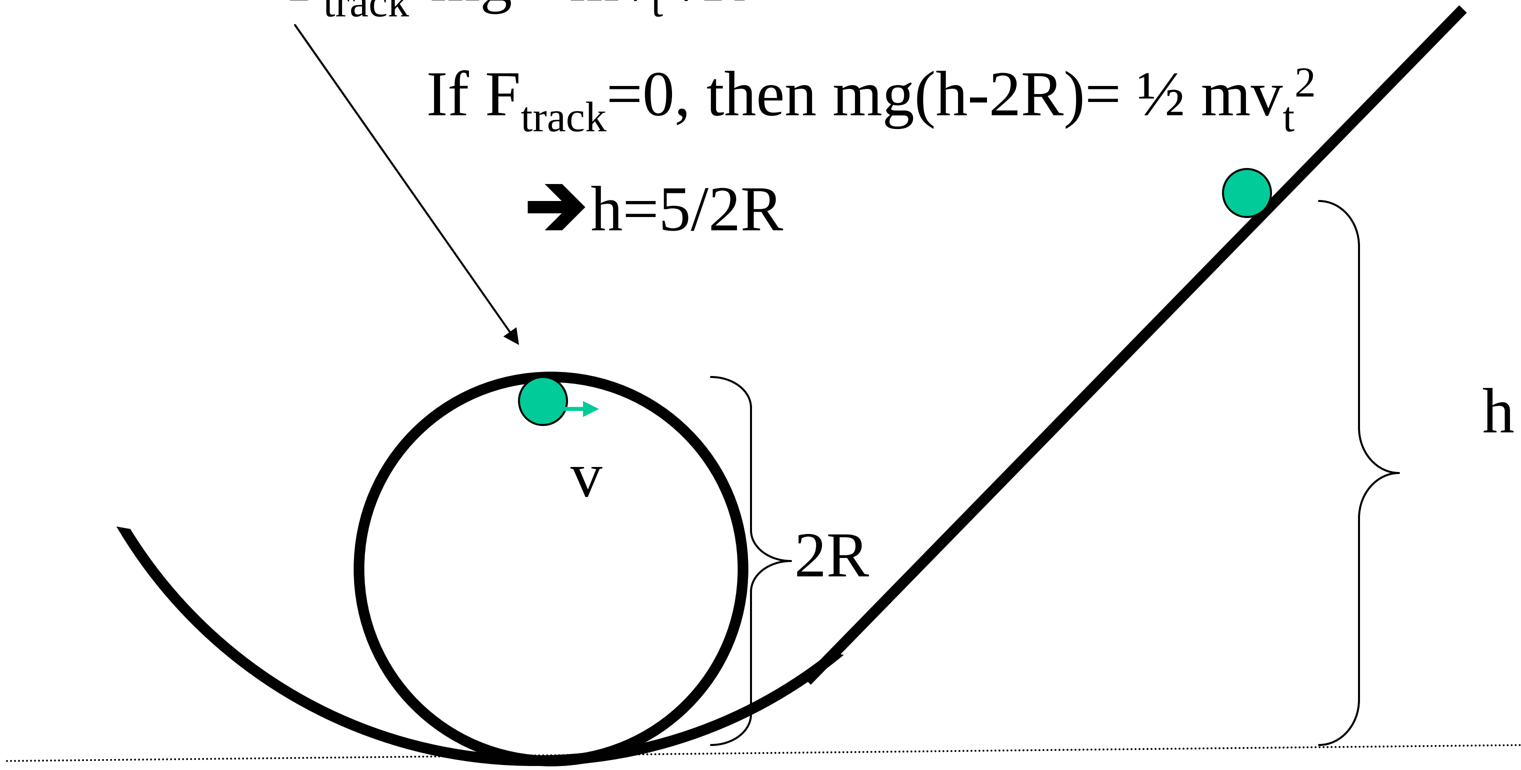
kinematic analysis: $v_f^2 = v_i^2 + 2a_0 (x_f - x_i) = 2(g \sin\theta - \mu_k g \cos\theta)L$

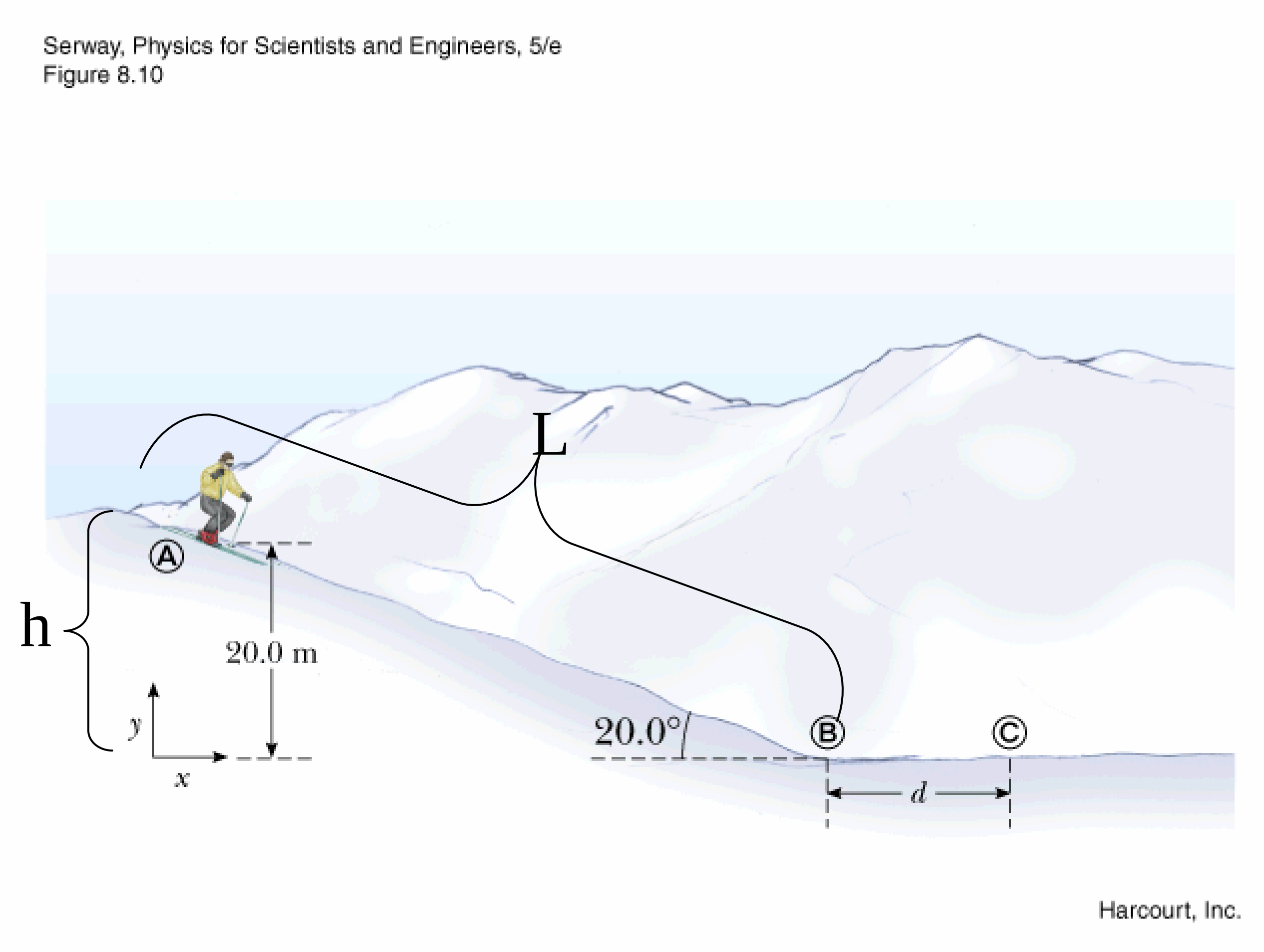
energy analysis: $W_{total} = mgh - \mu_k mg \cos\theta L = \frac{1}{2} m v_f^2$

$-F_{track} - mg = -mv_t^2/R$

If $F_{track}=0$, then $mg(h-2R) = \frac{1}{2} mv_t^2$

➔ $h = 5/2R$

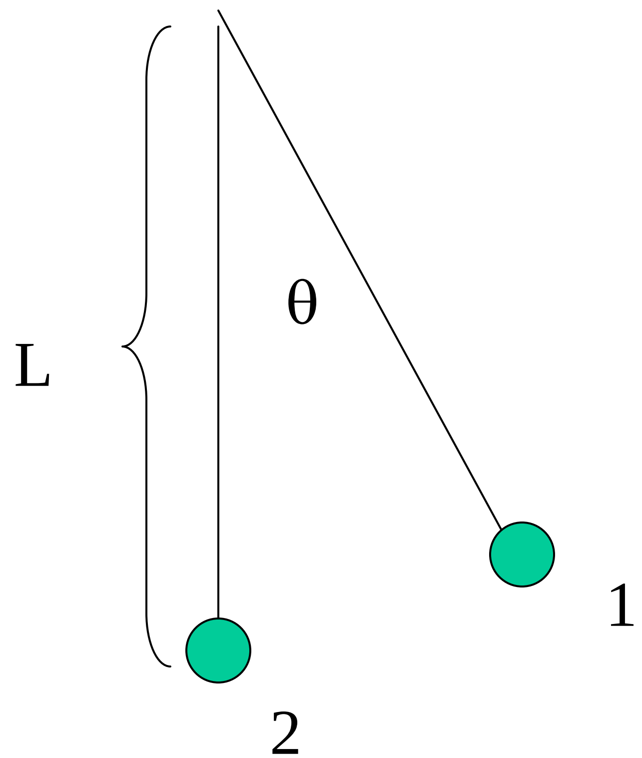




Suppose that the coefficient of friction between the skis and the snow is μ_k=0.2. What is the stopping distance d?

$mgh - \mu_k mg\cos\theta L - \mu_k mgd = 0$

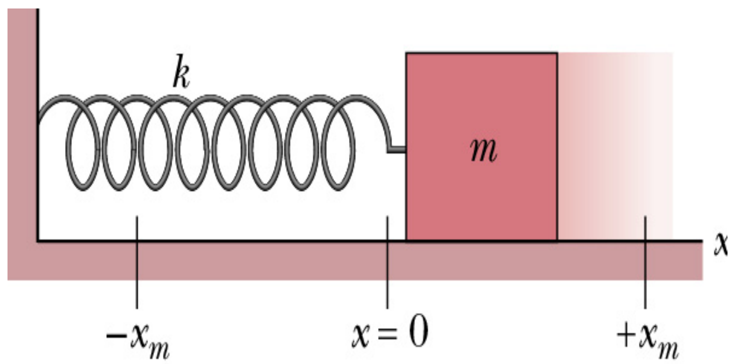
$d = h/\mu_k - L\cos\theta$



A ball attached to a rope is initially at an angle θ. After being released from rest, what is its velocity at the lowest point 2?

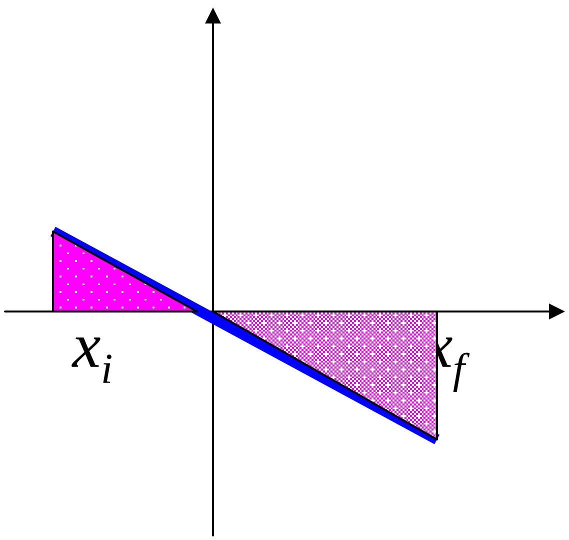
$$\sqrt{2gL(1-\cos\theta)}$$

Hooke's "law" (model force)



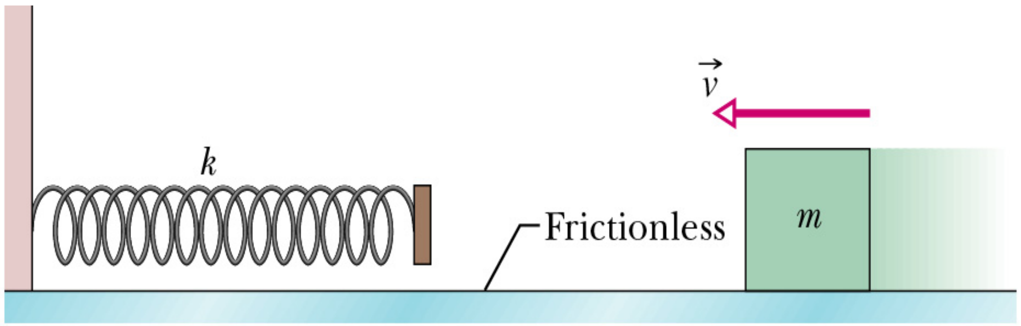
F = –kx

$$W_{i\to f} = \int_{x_i}^{x_f} -kx\,dx = -\tfrac{1}{2}k\left(x_f^2 - x_i^2\right)$$



Example problem:

A mass m with initial velocity v compresses a spring with Hooke's law constant k by a distance x_f. What is x_f when the mass momentarily comes to rest?



$$K_i = \tfrac{1}{2} m v^2$$

$$K_f = 0$$

$$W_{i \to f} = -\tfrac{1}{2} k x_f^{\,2}$$

$$W_{i \to f} = K_f - K_i \qquad \Rightarrow \tfrac{1}{2} k x_f^{\,2} = \tfrac{1}{2} m v^2$$

$$x_f = \sqrt{\frac{m}{k}}\, v$$