Energy

- Many types
- Units 1 Joule (J) = 1 kg-m^2/s^2
- Kinetic Energy – $K = ½mv^2$
  - (also rotational and vibrational)
- Gravitational Potential Energy – $U_g = mgh$
- Elastic (Spring) Potential Energy – $U_s = ½kx^2$
- Internal or Thermal Energy – E_{TH}
- Chemical Energy – E_{chem}
- Mass Energy – $E = mc^2$

- Has Science identified all the possible energies?
- Probably not
- Dark Energy
  - Causes the accelerating expansion of universe
  - Not really known what it is

FIGURE 10.1 Energy transformations occur within the system.

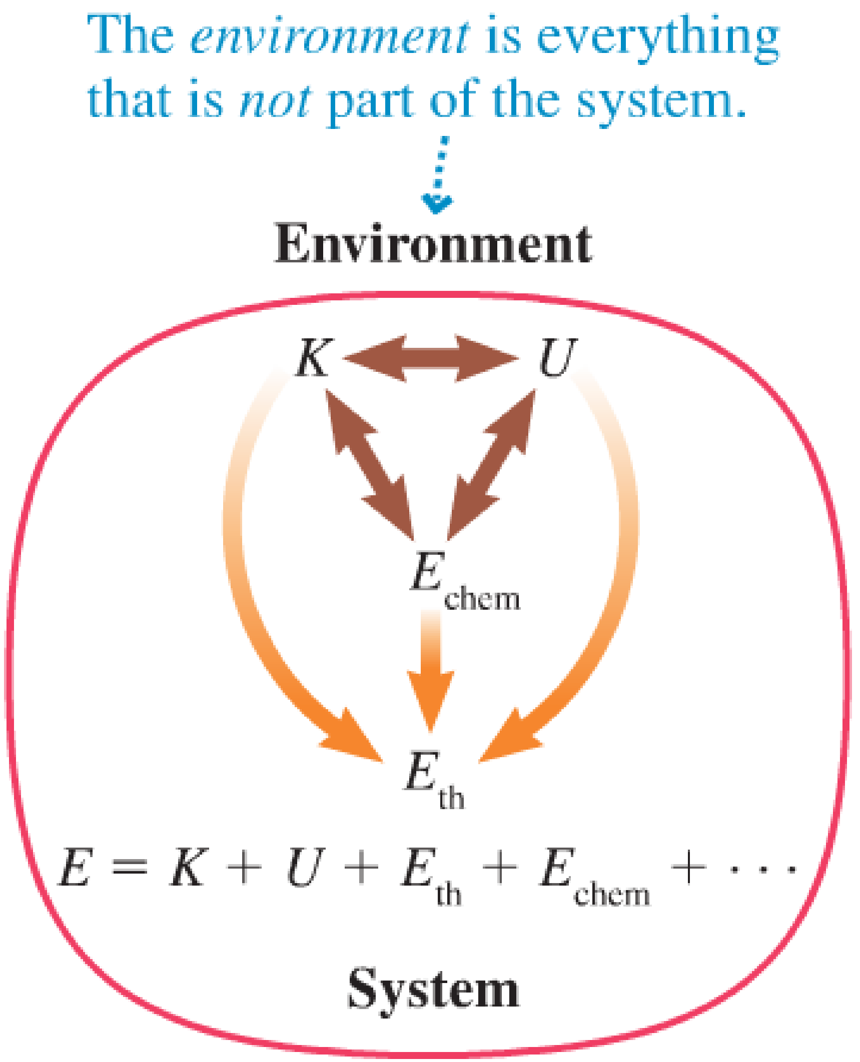
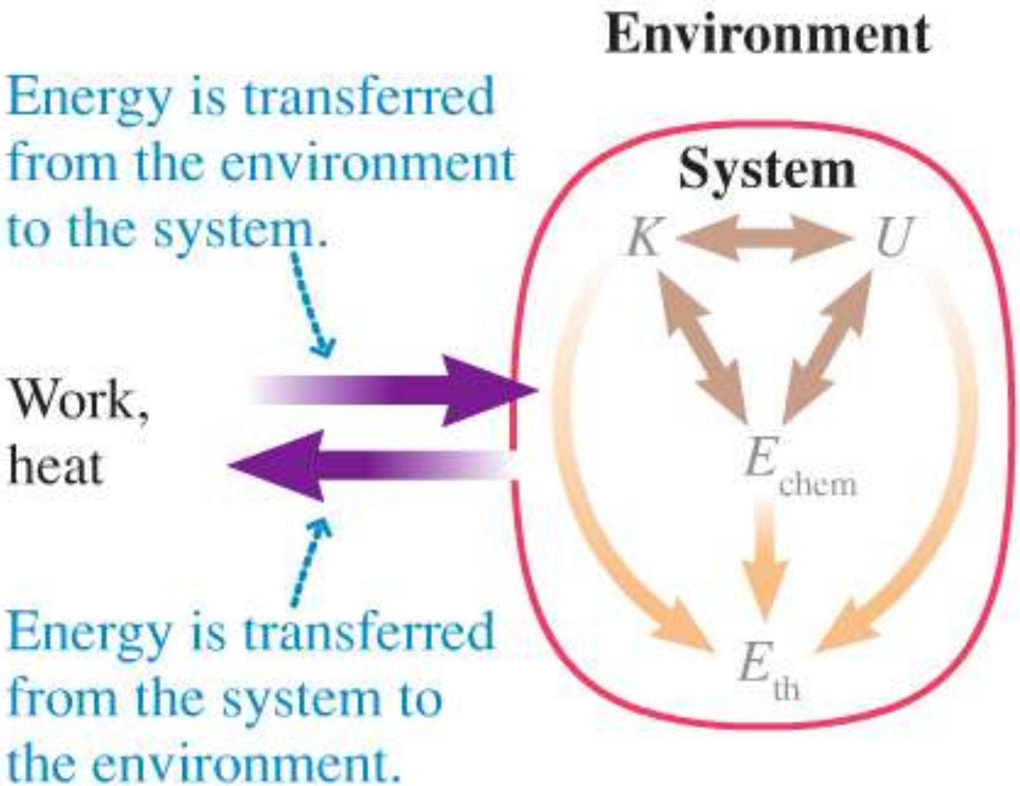
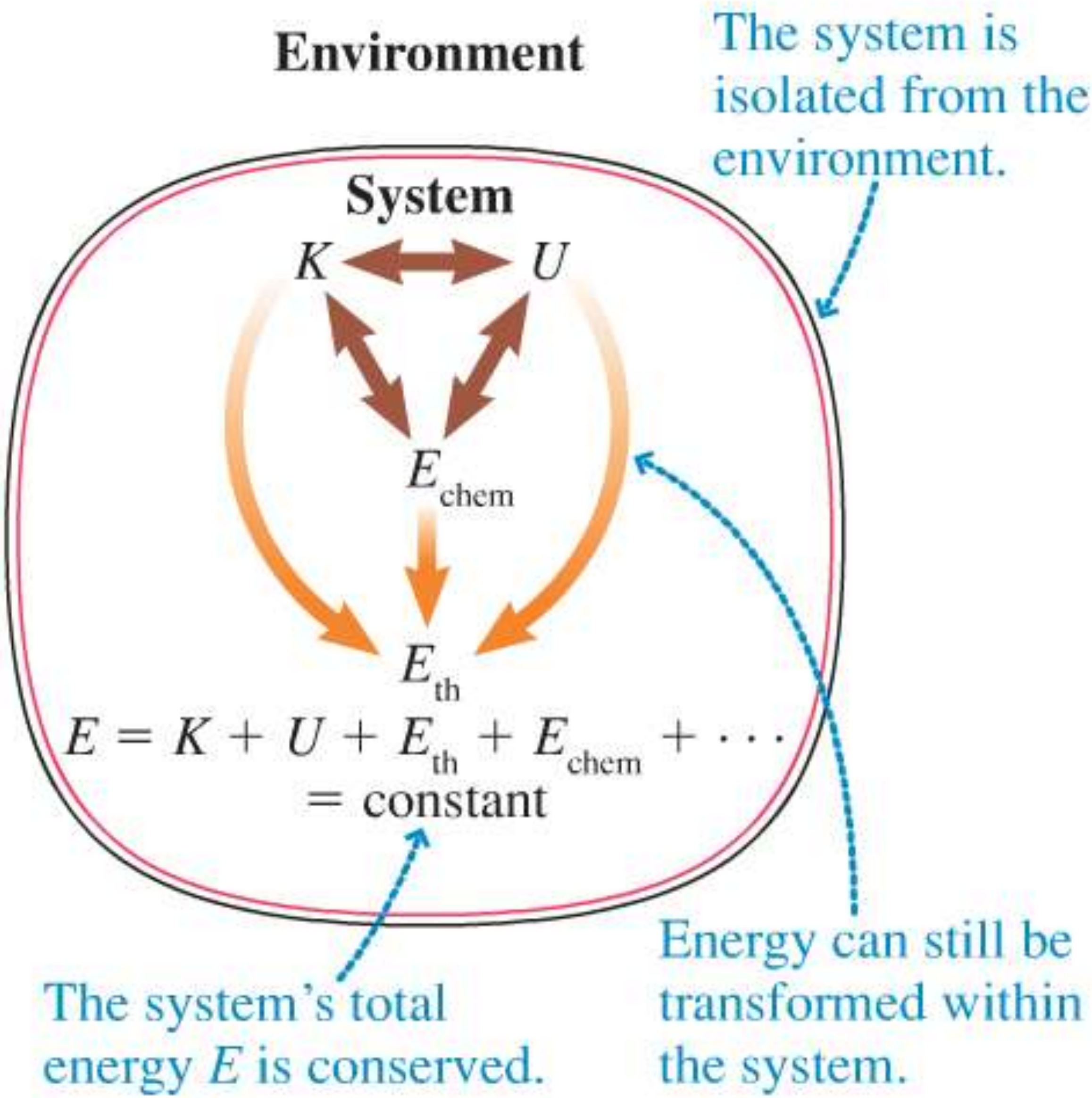


FIGURE 10.2 The basic energy model shows that work and heat are energy transfers into and out of the system, while energy transformations occur within the system.



$$W + Q = \Delta E_{sys}$$

FIGURE 10.3 An isolated system.

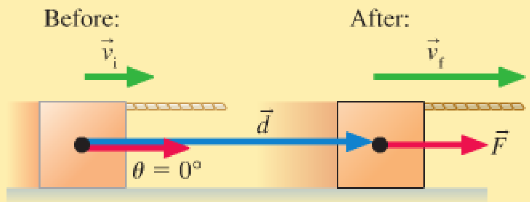
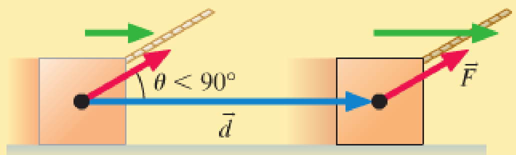
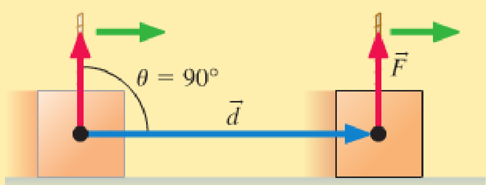
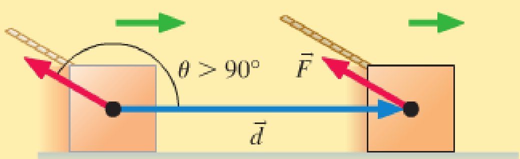
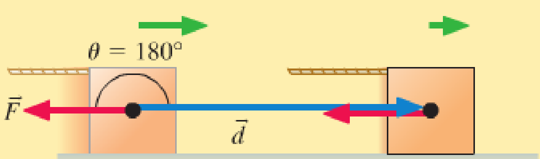


$$0 = \Delta E_{sys}$$

Heat and Work

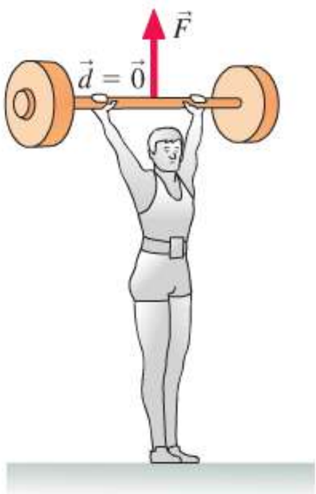
- Heat Q flows from a hotter to a cooler body (will discuss later)
- When an external object exerts a force on a system as it moves, work W is done.
- Internal forces occur is pairs (NIII), so no work is done by internal forces
- Work is a scalar.
- Magnitude depends on orientation of force and path.

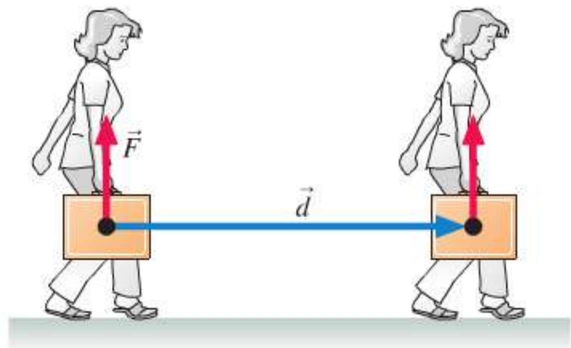
TACTICS BOX 10.1 Calculating the work done by a constant force

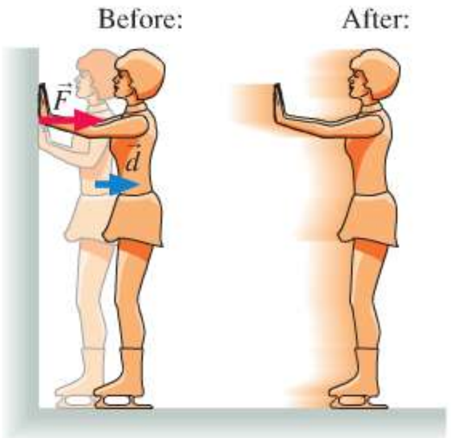
Direction of force relative to displacement	Angles and work done	Sign of W	Energy transfer
	$\theta = 0°$ $\cos\theta = 1$ $W = Fd$	+	The force is in the direction of motion. The block has its greatest positive acceleration. K increases the most: **Maximum energy transfer to system.**
	$\theta < 90°$ $W = Fd\cos\theta$	+	The component of force parallel to the displacement is less than F. The block has a smaller positive acceleration. K increases less: **Decreased energy transfer to system.**
	$\theta = 90°$ $\cos\theta = 0$ $W = 0$	0	There is no component of force in the direction of motion. The block moves at constant speed. No change in K: **No energy transferred.**
	$\theta > 90°$ $W = Fd\cos\theta$	−	The component of force parallel to the displacement is opposite the motion. The block slows down, and K decreases: **Decreased energy transfer *out* of system.**
	$\theta = 180°$ $\cos\theta = -1$ $W = -Fd$	−	The force is directly opposite the motion. The block has its greatest deceleration. K decreases the most: **Maximum energy transfer *out* of system.**

Exercises 5–6

Forces that do no work







If the object undergoes no displacement while the force acts, no work is done.

This can sometimes seem counterintuitive. The weightlifter struggles mightily to hold the barbell over his head. But during the time the barbell remains stationary, he does no work on it because its displacement is zero. Why then is it so hard for him to hold it there? We'll see in Chapter 11 that it takes a rapid conversion of his internal chemical energy to keep his arms extended under this great load.

A force perpendicular to the displacement does no work.

The woman exerts only a vertical force on the briefcase she's carrying. This force has no component in the direction of the displacement, so the briefcase moves at a constant velocity and its kinetic energy remains constant. Since the energy of the briefcase doesn't change, it must be that no energy is being transferred to it as work.

(This is the case where $\theta = 90^\circ$ in Tactics Box 10.1.)

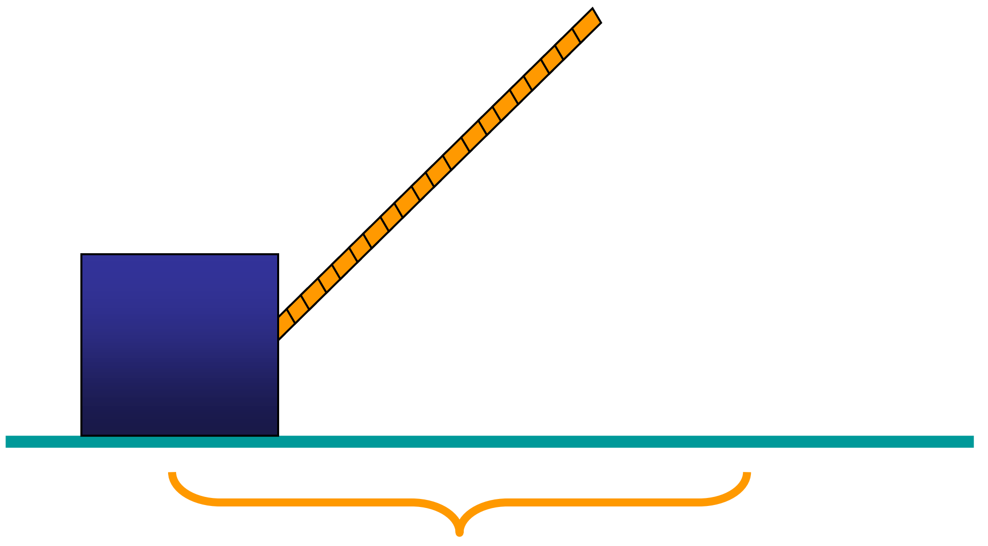
If the part of the object on which the force acts undergoes no displacement, no work is done.

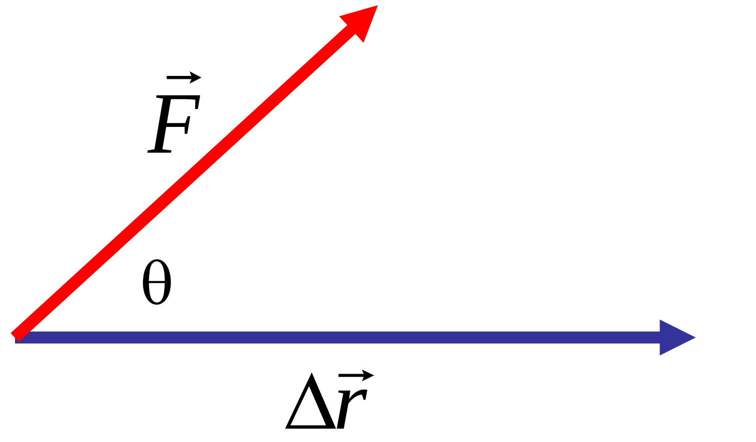
Even though the wall pushes on the skater with a normal force $\vec{n}$ and she undergoes a displacement $\vec{d}$, the wall does no work on her, because the point of her body on which $\vec{n}$ acts—her hands—undergoes no displacement. This makes sense: How could energy be transferred as work from an inert, stationary object? So where does her kinetic energy come from? This will be the subject of much of Chapter 11. Can you guess?

Biological Systems and Work

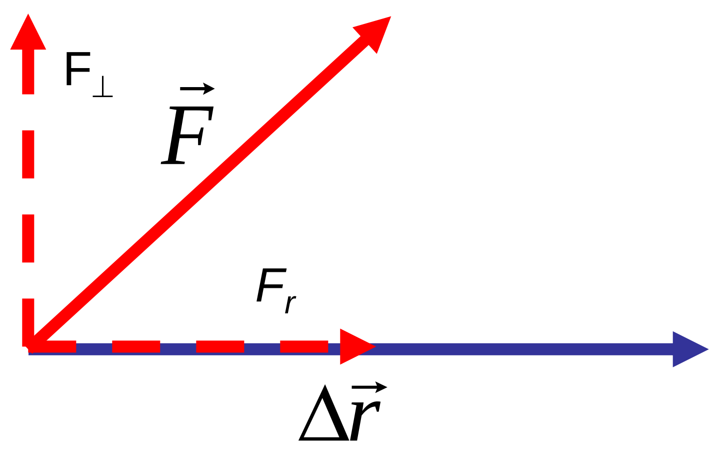
- To get muscle to exert a continuous force takes a constant supply of energy. Exhaust supply and get tired.
- Skeleton is fairly rigid but can be used as a support. Must still use muscle to keep skeleton aligned. Less energy needed.
- Using body weight uses almost no energy.

Work in Vector format



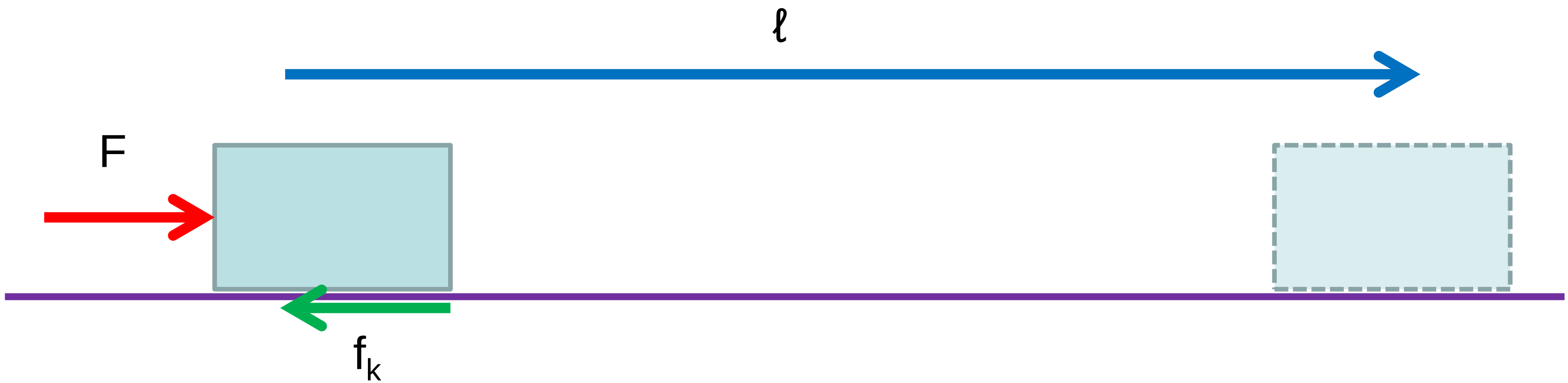


$$W = \vec{F}\cdot\Delta\vec{r} = F\Delta r\cos\theta$$



$$\begin{aligned} W &= \vec{F}\cdot\Delta\vec{r} \\ &= F_r\Delta r \\ &= F_y\Delta x + F_x\Delta y + F_z\Delta z \end{aligned}$$

Work and Friction



Let $F = f_k$ so $a = 0$ and velocity does not change.

$$W_{ext} = \Delta E$$

$$W_{ext} = F\ell - f_k\ell \Rightarrow \Delta E = 0$$

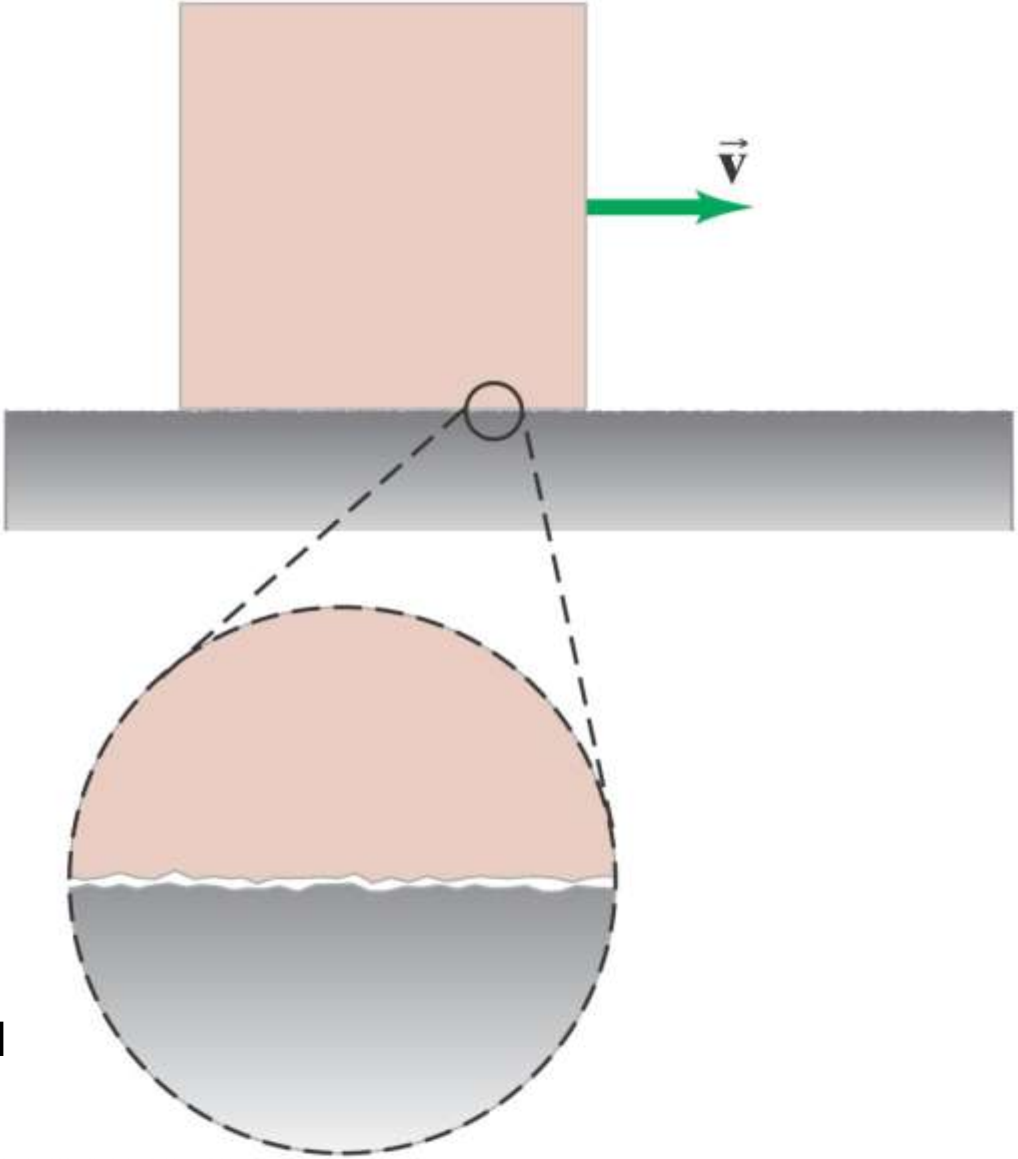
But $\Delta E = \Delta E_{TH}$ increases, block gets warmer!

How can this be?

- Friction is a complex force made up of the forces between bumps on surfaces.

- Since the surfaces are not rigid, ℓ is not distance these forces all act over.

- For small distances, good enough and $\Delta E_{TH} \cong 0$



Using Work Energy Methods

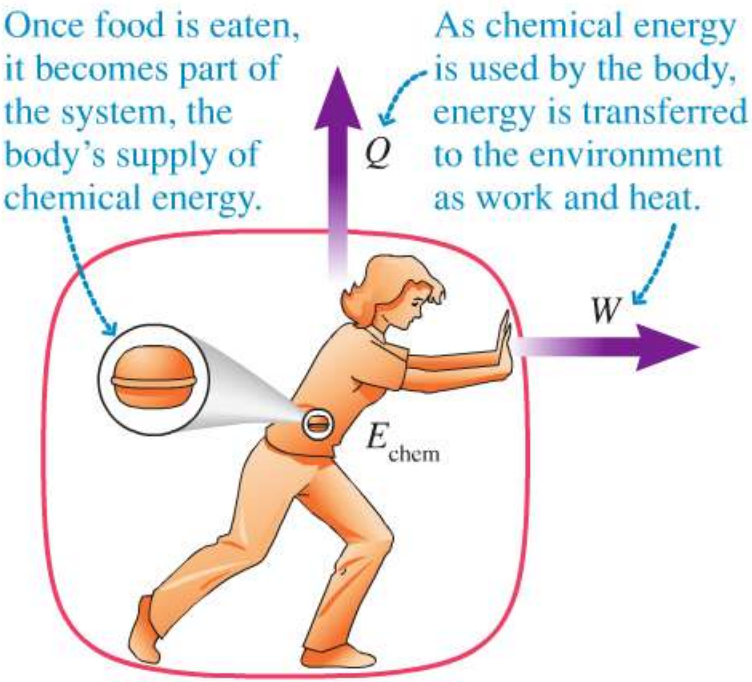
- Use if interested in changes of height or speed
- Identify the system (often connected by ropes or springs!)
- Identify objects exerting forces on system
- Note gravity force accounted by *mgh* already.
- Internal system forces do no work.
- Look at $t = 0$ and t_{final}, how has the energy of each member of the system changed?

Power

- Rate of change of energy or at which work is done
- $P = \frac{\Delta E}{\Delta t}$, amount of energy transformed in time Δt
- $P = \frac{W}{\Delta t}$, amount of work done in time Δt
- $P = \frac{W}{\Delta t} = \frac{F_x \Delta x}{\Delta t} = F_x \frac{\Delta x}{\Delta t} = Fv$, rate of energy transfer by *F* acting on object travelling at *v*
- 1 Watt (W) = 1 Joule/second
- 1 Horsepower (Hp) = 745 W

Efficiency

FIGURE 11.4 Energy of the body, considered as the system.



- When a complex object like a person or engine does external work it must use internal energy (food or fuel).
- Not all that internal energy goes to do work
- Breathing/circulation etc also need energy
- Heat is also produced

Efficiency

- e = Work done / Energy consumed

- Always $e < 1$ (Law of thermodynamics)

- for people $e \cong 25\%$
- *Or* $e = P_{out} / P_{in}$

Energy and the Body - Food

- Food = chemical energy
- Food + $O_2 \Rightarrow CO_2$ + energy
- Energy $\Rightarrow$ heat + ATP
- ATP is fuel molecule of cells
- metabolism slow/burning fast give same energy
  - (use bomb calorimeter to measure E in food)
- Amount of O_2 is proportional to energy
  - (measure O_2 consumption to measure body E needs)

Energy and the Body - Food

- ATP end product
- Intermediate fuel storage as glycogen and glucose in muscle tissue and liver
  - Can be converted to ATP quickly
  - ~400 g
  - Endurance athletes use it all up and “hit the wall”
- Long term storage as fat
  - Slower to convert

Energy and the Body - Food

Food	Energy in 1 g (KJ)
Protein	17
Fat	38
Carbohydrates	17
Ethanol (alcohol)	29
Organic acids	13
Polyols (sugar alcohols, sweeteners)	10
Fibre	8

Source: Wikipedia

Units 1 Kcal = 4.19 KJ

Example

Food	Energy in 1 g (KJ)
Protein	17
Fat	38
Carbohydrates	17
Ethanol (alcohol)	29
Organic acids	13
Polyols (sugar alcohols, sweeteners)	10
Fibre	8

3.5 g * 38 KJ/g + 12g * 17KJ/g + 4g*17KJ/g =405 KJ

405 Kj / 4.19 KJ/Kcal = 97 KCal

Example

Food	Energy in 1 g (KJ)
Protein	17
Fat	38
Carbohydrates	17
Ethanol (alcohol)	29
Organic acids	13
Polyols (sugar alcohols, sweeteners)	10
Fibre	8

How many grams of fat per serving?

Energy and the Body - Output

TABLE 11.3 Energy use at rest

Organ	Resting power (W) of 68 kg individual
Liver	26
Brain	19
Heart	7
Kidneys	11
Skeletal muscle	18
Remainder of body	19
Total	**100**

Energy and the Body - Output

TABLE 11.4 Metabolic power use during activities

Activity	**Metabolic power (W) of 68 kg individual**
Typing	125
Ballroom dancing	250
Walking at 5 km/h	380
Cycling at 15 km/h	480
Swimming at a fast crawl	800
Running at 15 km/h	1150

People are very good at converting food to fat (~100% efficient).

So a person who needs 2000 Kcal a day but eats 2400 Kcal of food, coverts 400 Kcal to fat.

(how may grams?)

Rating Exercise

http://siliconangle.com/blog/2010/01/04/the-suunto-t6c-is-a-wearable-sports-laboratory/

- Devices measure O2/CO2 and thus the total energy E used
- = total food need to consume
- $E_{out} = E_{consumed}$
- External work W done lifting and lowering legs is much less b/c most of the energy go to heat and internal work (breathing, beating heart, etc.).
- $W = e \times E$

Problem may tell you the energy needed for the exertion. Efficiency not a factor.

Problem may tell you mechanical details so you can calculate the mechanical work output. Now use efficiency number to figure out energy consumed.

General Example

A person has a normal metabolic rate of 100 W. He is measuring doing 100 W of mechanical work. Assume he is 25% efficient.

(a) What is his metabolic rate now?

(b) At what rate does he produce heat?

(c) How much extra heat must he get rid of by flushing, sweating or removing clothing?

We know $E_{food} = W_{mechanical} + Q_{heat}$

Or $P_{food} = P_{work} + P_{heat}$

Now, before he exercises $P_{work} = 0$ and

$$P_{food} = P_{heat} = 100 \text{ W}.$$

Now he exercises so his MR (metabolic rate) goes up

$$P_{food}^{NEW} = (P_{work} = 100 \text{ W}) + P_{heat}^{NEW}$$

Now efficiency is $e = P_{work}/P_{food}$

So $P_{food}^{NEW} = P_{work}/0.25 = 400$ W.

Now we can find the P_{heat}^{NEW}

$$400 \text{ W} = 100 + P_{heat}^{NEW}$$

Or $P_{heat}^{NEW} = 400 \text{ W} – 100 \text{ W} = 300 \text{ W}$

The excess heat is the difference between how much he produces now and when he doesn’t exercise.

$P_{excess\ heat} = 300 \text{ W} – 100 \text{ W} = 200 \text{ W}$

Example

Playing badminton “burns” 4 Kcal/hr per kg of body mass. How long does a 65-kg player need to play to burn off 150 Kcal?

- The 65-kg player burns 4 * 65 Kcal/hr = 260 Kcal/hr
- 150 Kcal / 260 Kcal/hr = 0.58 Hr = 35 min

Weightlifter "benches" 80-kg 200 times through 40 cm. How many KJ burned? Assume e = 25%.

- Note applying muscle requires work up and down if you don't drop the weight.
- Work = 200 $\times$ mgh $\times$ 2 = 200 $\times$ 80 $\times$ 9.8 $\times$ .4 $\times$ 2

  = 313.6 KJ
- E = W/e = 313.6 KJ / 0.25 = 1254 KJ