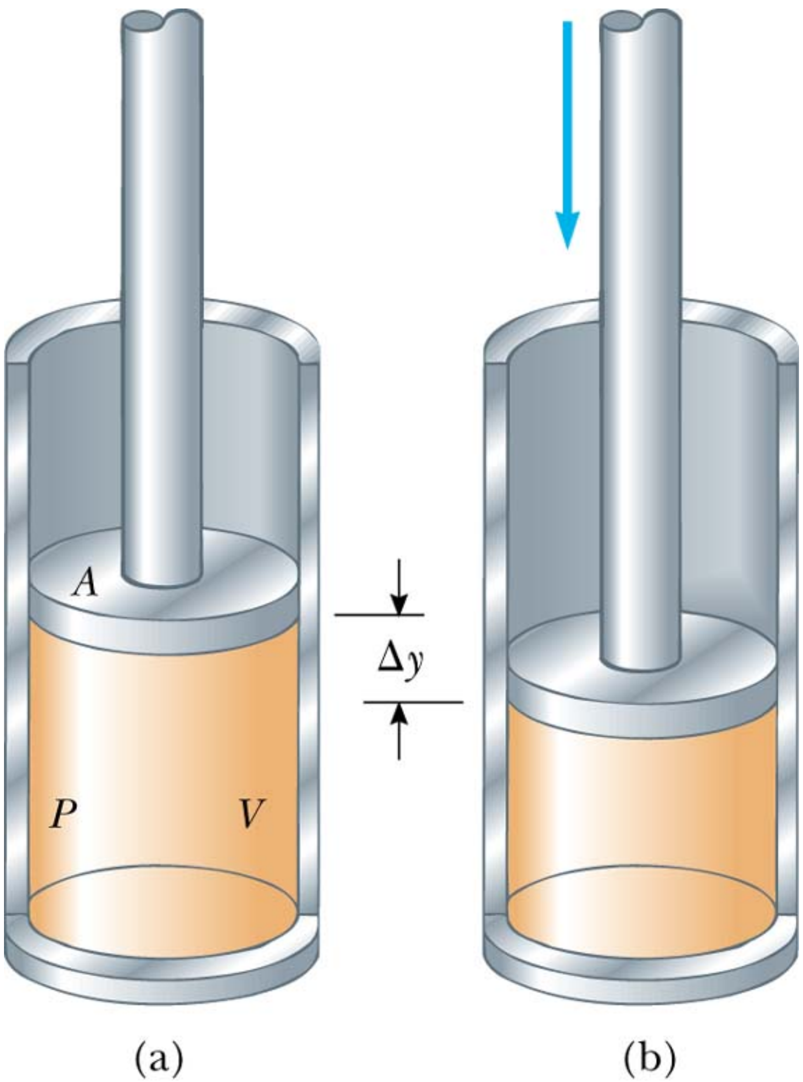
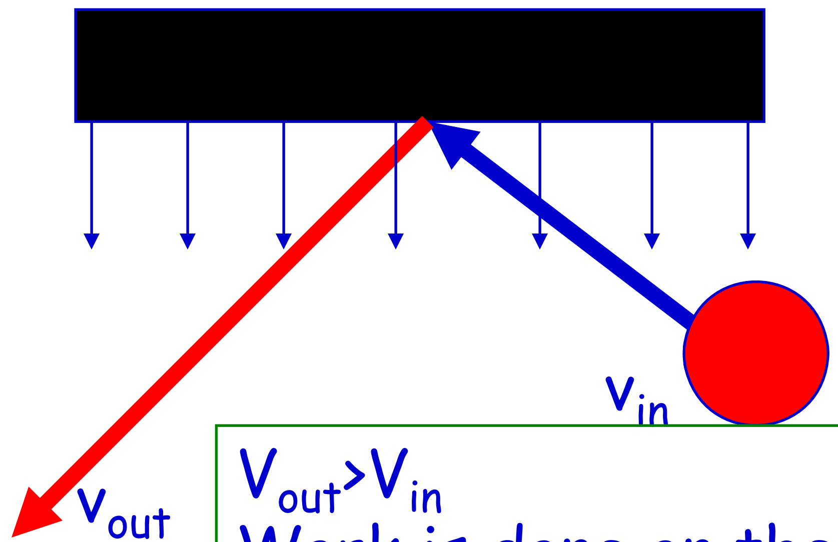
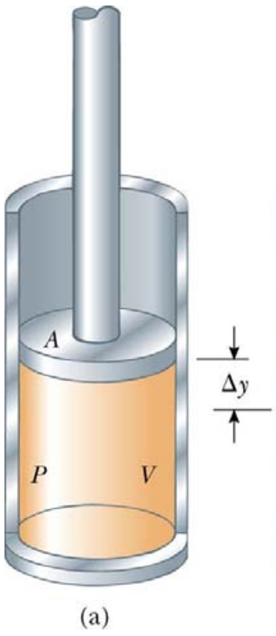
Thermodynamics



Piston is moved downward slowly so that the gas remains in thermal equilibrium:
The temperature is the the same at all times in the gas, but can change as a whole.



$V_{out} > V_{in}$
Work is done on the gas



Isobaric compression

Let's assume that the pressure does not change while lowering the piston (isobaric compression).

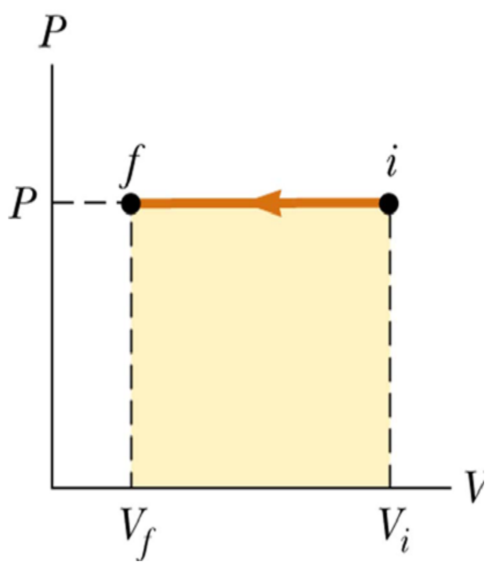
$W = -F\Delta y = -PA\Delta y \qquad (P = F/A)$

$W = -P\Delta V = -P(V_f - V_i) \qquad$ (in Joules)

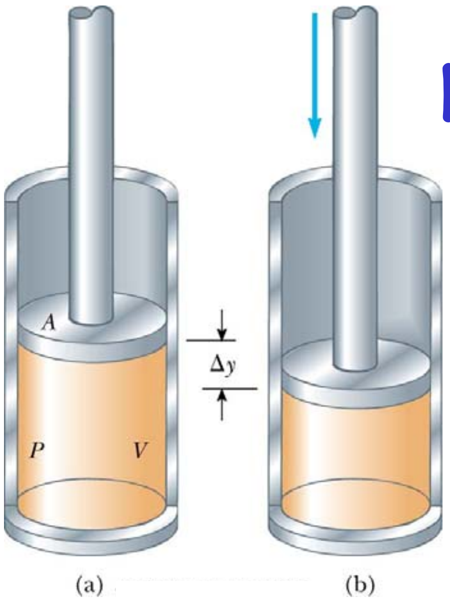
W: work done on the gas

+ if $\Delta V < 0$

- if $\Delta V > 0$

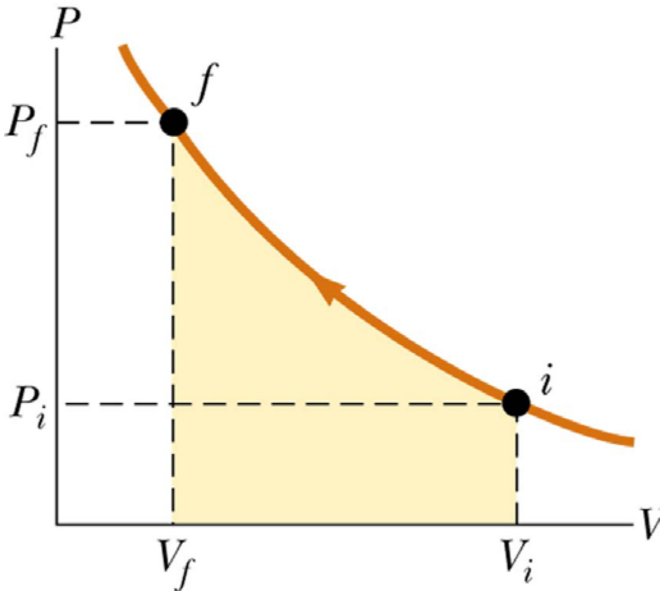


This corresponds to the area under the curve in a P-V diagram



Non-isobaric compression

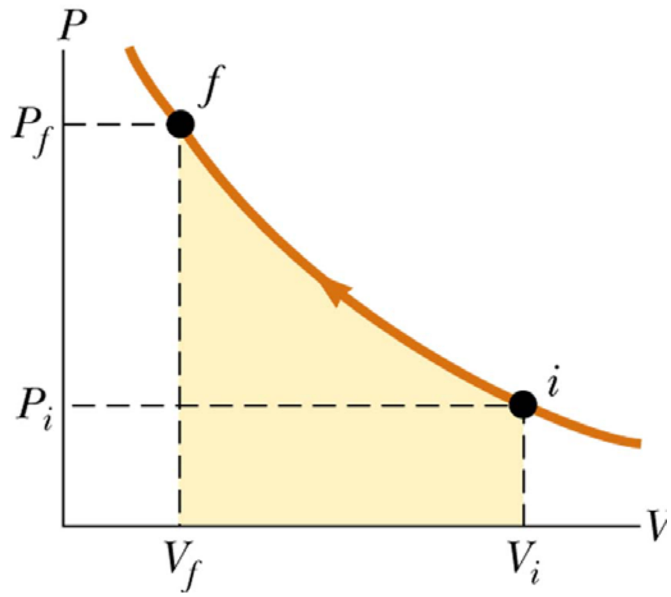
In general, the pressure can change when lowering the piston.



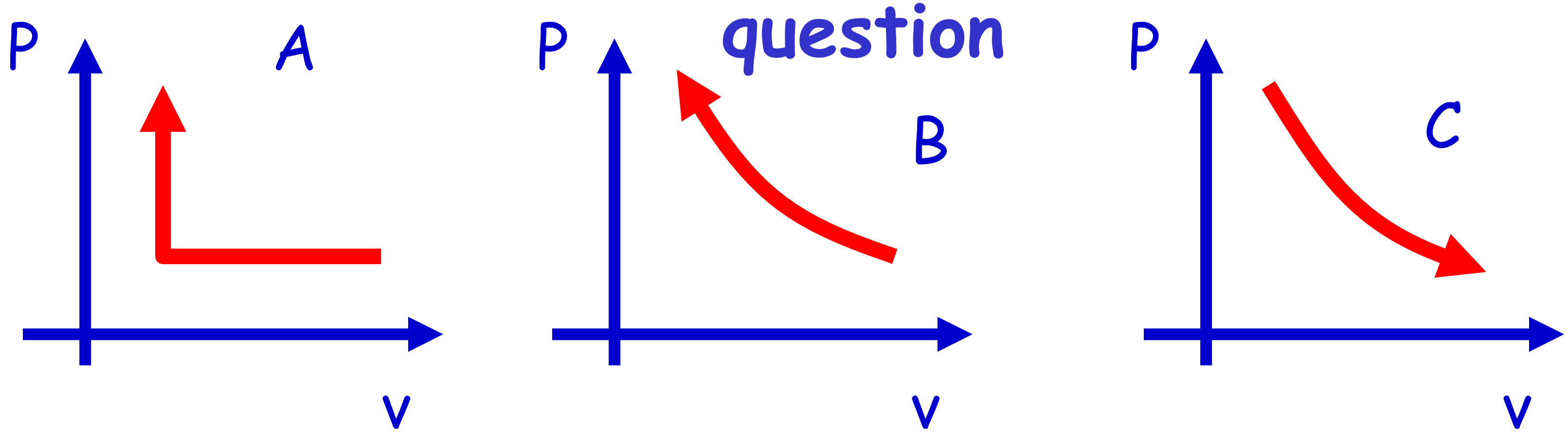
The work done on the gas when going from an initial state (i) to a final state (f) is the area under the P-V diagram.

The work done by the gas is the opposite of the work done on the gas.

Work done on gas: signs.



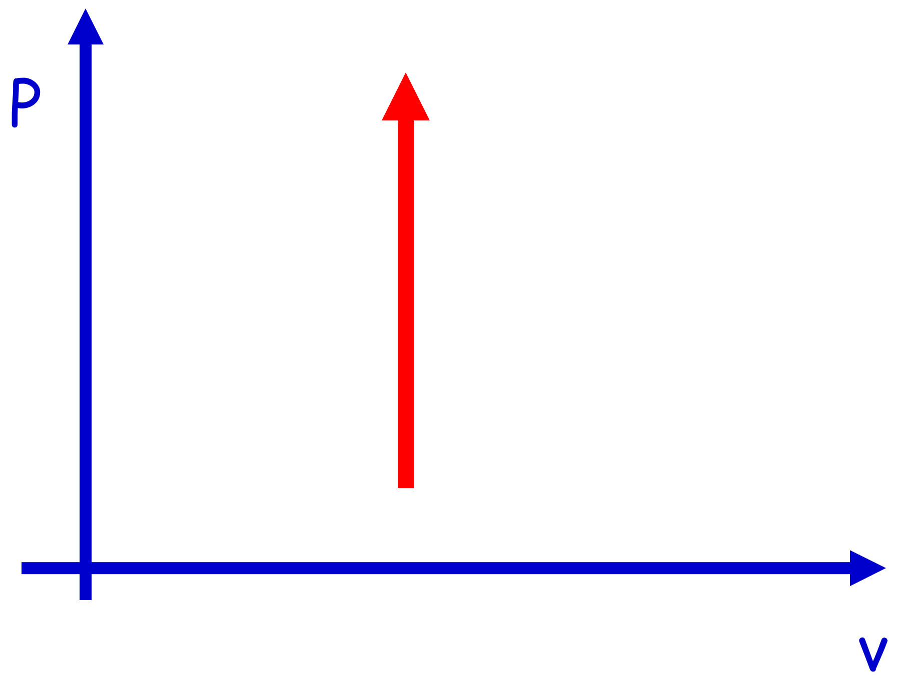
If the arrow goes from right to left, positive work is done on the gas. If the arrow goes from left to right, negative work is done on the gas (the gas has done positive work on the piston) question



In which case is the work done on the gas largest?

The area under the curves in cases B and C is largest (i.e. the absolute amount of work is largest). In case C, the volume becomes larger and the pressure lower (the piston is moved up) so work is done by the gas (work done on the gas is negative). In case B the work done on the gas is positive, and thus largest.

Isovolumetric process



Work done on/by gas: $W=-P\Delta V=0$

First Law of Thermodynamics

By performing work on an object the internal energy can be changed

Think about deformation/pressure

Think about heat transfer

By transferring heat to an object the internal energy can be changed

The change in internal energy depends on the work done on the object and the amount of heat transferred to the object.

Remember: the internal energy is the energy associated with translational, rotational, vibrational motion of atoms and their potential energy

First Law of thermodynamics

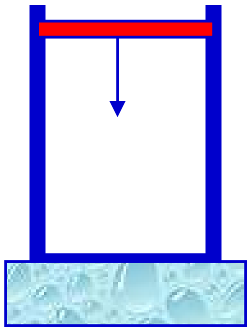
$$\Delta U = U_f - U_i = Q + W$$

ΔU=change in internal energy
Q=energy transfer through heat (+ if heat is transferred to the system)
W=energy transfer through work (+ if work is done on the system)

This law is a general rule for conservation of energy

First law: examples 1) isobaric process

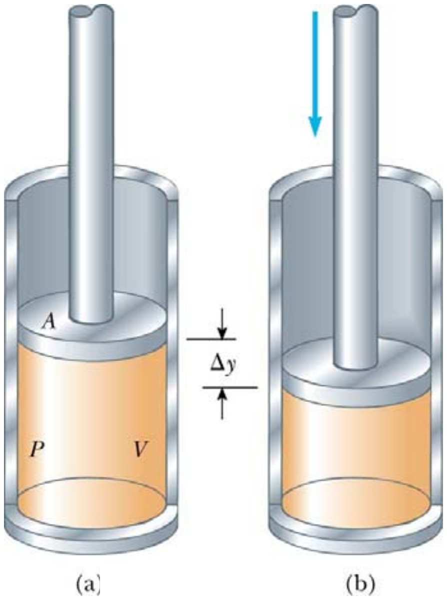
A gas in a cylinder is kept at 1.0×10^5 Pa. The cylinder is brought in contact with a cold reservoir and 500 J of heat is extracted. Meanwhile the piston has sunk and the volume changed by 100 cm^3. What is the change in internal energy?



$Q = -500$ J
$W = -P\Delta V = -1.0 \times 10^5 \times -100 \times 10^{-6} = 10$ J
$\Delta U = Q + W = -500 + 10 = -490$ J

In an isobaric process both Q and W are non-zero.

First Law: examples: 2) Adiabatic process



A piston is pushed down rapidly. Because the transfer of heat through the walls takes a long time, no heat can escape.
During the motion of the piston, the temperature has risen 100 ^{0}C. If the container has 10 moles of an ideal gas, how much work has been done during the compression?

Adiabatic: No heat transfer, Q=0

$\Delta U = Q + W = W$

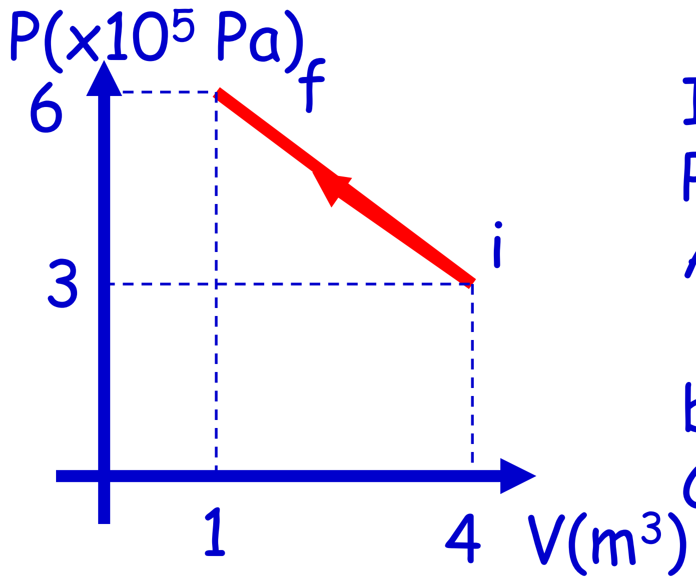
$\Delta U = (3/2)nR\Delta T = (3/2)\times 10\times 8.31\times 100 = 12465$ J

(ideal gas: internal energy is kinetic energy $U=(3/2)nRT$)

12465 J of work has been done on the gas.

Why can we not use $W=-P\Delta V$???

First Law: examples 3) general case



In ideal gas is compressed (see P-V diagram).

A) What is the change in internal energy

b) What is the work done on the gas?

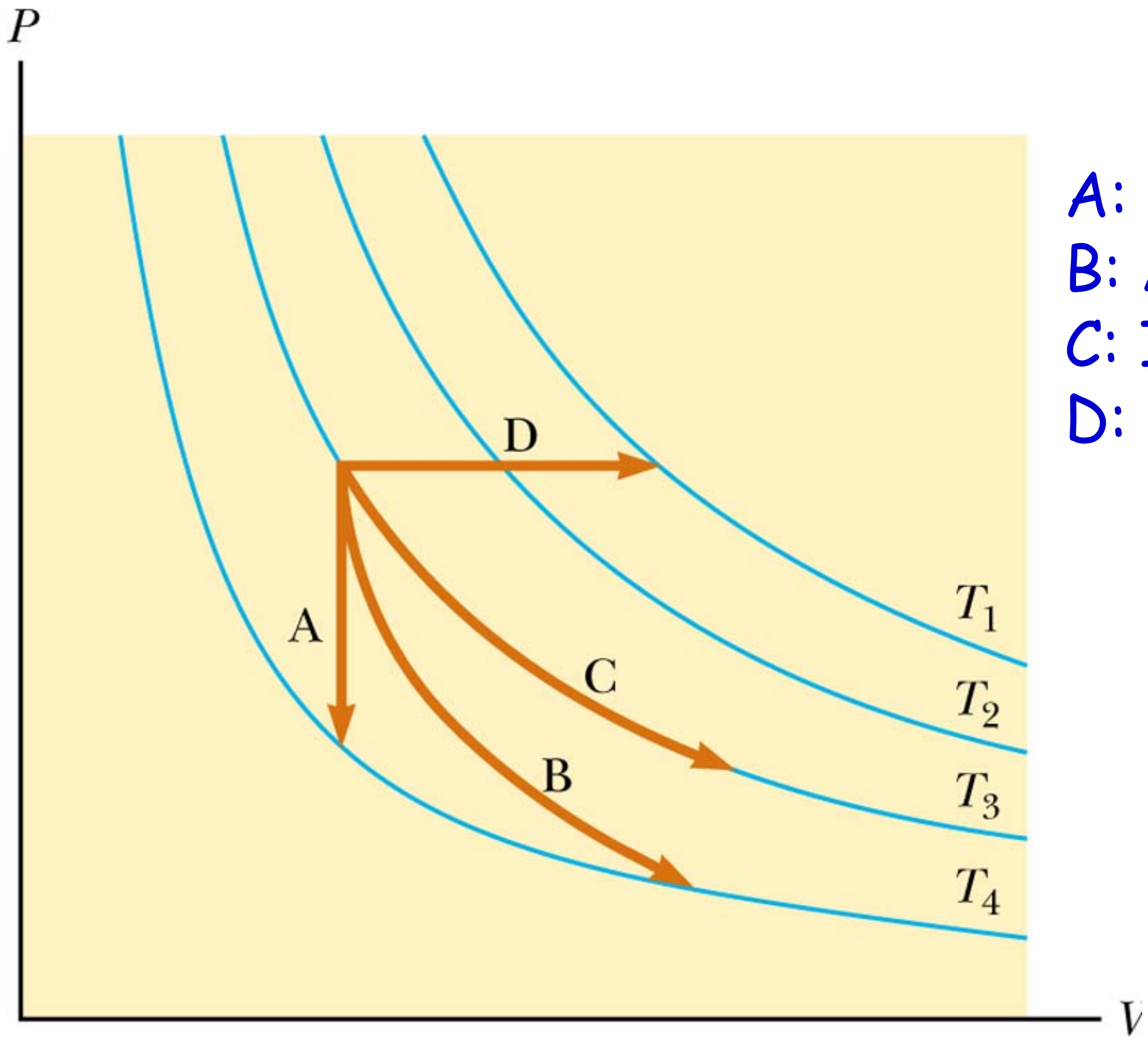
C) How much heat has been transferred to the gas?

A) $U=(3/2)nRT$ and $PV=nRT$ so, $U=(3/2)PV$ & $\Delta U=(3/2)\Delta(PV)$
$\Delta U=3/2(P_fV_f-P_iV_i)=3/2[(6E+05)\times1 - (3E+05)\times4)=-9E+5$ J

B) Work: area under the P-V graph: $(9+4.5)\times10^5=13.5\times10^5$
(positive since work is done on the gas)

C) $\Delta U=Q+W$ so $Q=\Delta U-W=(-9E+5)-(13.5E+5)=-22.5E+5$ J
Heat has been extracted from the gas.

Types of processes



A: Isovolumetric $\Delta V=0$
B: Adiabatic $Q=0$
C: Isothermal $\Delta T=0$
D: Isobaric $\Delta P=0$

$PV/T=\text{constant}$

Metabolism

$$\Delta U = Q + W$$

Work done (negative)

Heat transfer: Negative

body temperature < room temperature

Change in internal energy: Must be increased: Food!

Metabolic rate

$$\frac{\Delta U}{\Delta t} = \frac{Q}{\Delta t} + \frac{W}{\Delta t}$$

Metabolic rate: rate in which food and oxygen are transformed into internal energy (to balance losses due to heat loss and work done).

Body's efficiency: $\dfrac{|W/\Delta t|}{|\Delta U/\Delta t|}$

Body's efficiency

TABLE 12.1 Oxygen Consumption and Metabolic Rates for Various Activities for a 65-kg Male[a]

Activity	O_2 use rate (mL/min · kg)	Metabolic rate (kcal/h)	Metabolic rate (W)
Sleeping	3.5	70	80
Light activity (dressing, slow walking, desk work)	10	200	230
Moderate activity (walking briskly)	20	400	465
Heavy activity (basketball, (fast breast stroke)	30	600	700
Extreme activity (bicycle racing)	70	1 400	1 600

$\Delta U/\Delta t$~oxygen use rate can be measured

TABLE 12.3 Metabolic Rate, Power Output, and Efficiency for Different Activities[a]

Activity	Metabolic rate $\frac{\Delta U}{\Delta t}$ (W)	Power Output $\frac{W}{\Delta t}$ (W)	Efficiency e
Cycling	505	96	0.19
Pushing loaded coal cars in a mine	525	90	0.17
Shoveling	570	17.5	0.03

$\Delta W/\Delta t$ can be measured