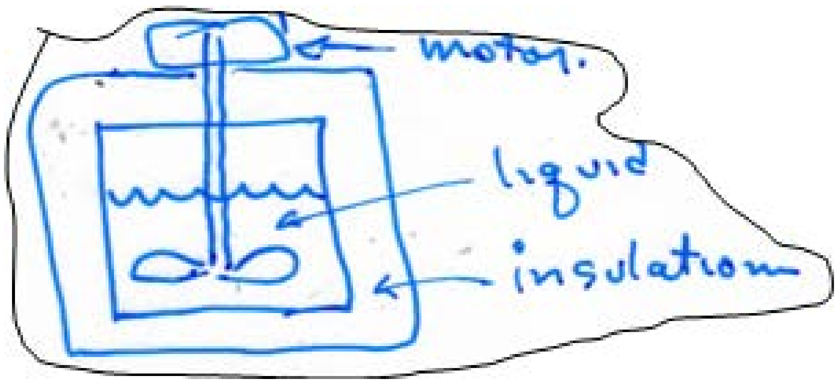
Two More Examples:

T of water (the system) is increased 10°C by two different paths:

1) **by friction** from **stirring by a motor from surroundings** while thermally insulated from the motor.

What are q and w?



q = 0 (insulated)

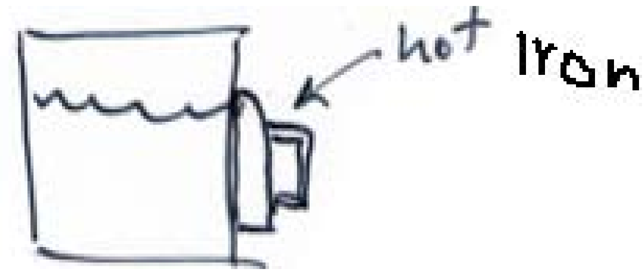
w = + (motor does work on water)

$\Delta U = q + w$ (Eq. 2.26, page 24)

$\Delta U = w$

2) by a **hot iron** in **thermal contact** with the system.

What are q and w?



q = + because temperature of iron decreased; w=0; $\Delta U = q$

Lesson: q and w depend on **path,** but **ΔU is independent of path** because initial and final states of system are **same** in both cases!!!!!

Relevance of $\Delta U = \quad q \quad + \quad w$

Living things are able to get the ***maximum*** work from food. (But typically not all of the energy can be turned to work.)

If we choose to make a bonfire of our food

$\Delta U = q_{max\ out}$ **and** **useful** $w = 0$

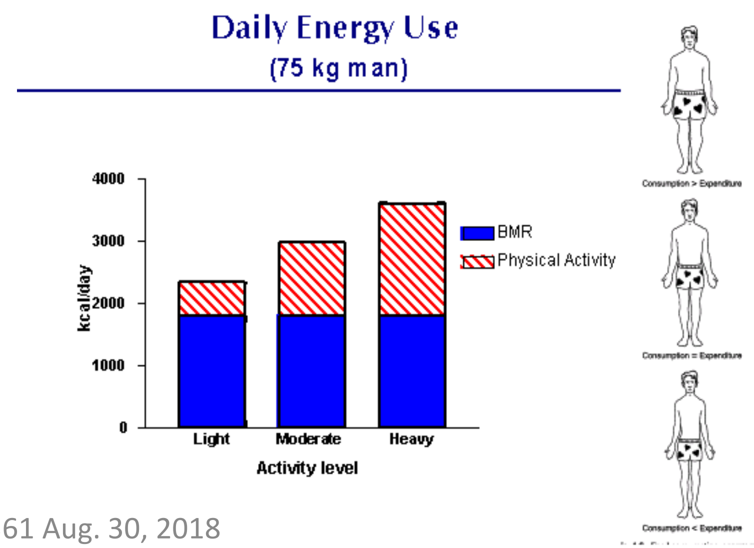
(useful work is anything except pushing back the atmosphere due to volume change)

If we choose to eat our food, the same reaction: food + Oxygen→ $CO_2 + H_2O$

$\Delta U = q_{min\ out} \quad + \quad w_{max\ out}$

What work is being done with the 2000 kcal/day we require doing nothing?

(**BMR** = basic metabolic rate)



Living things have evolved to get the maximum possible useful work from the ΔU of burning food.

they do this ***reversibly***, i.e., nearly at equilibrium

ATP (adenosine triphosphate) is the major currency of work in our cells;

ATP is continually used and rebuilt throughout the day.

Amazingly, if you add up the amount of ATP that is built each day, it would roughly equal the **weight of your entire body.**
This ATP is spent in many ways: to power muscles, to make sure that enzymes perform the proper reactions, to **PUMP IONS**, +100,000 other...
but roughly a third of the ATP made by our cells is spent to power the sodium-potassium pump (a PROTEIN).
Life requires **cells** to have **high K^+ concentration**, but **blood** has **high Na^+**

Sodium-Potassium Pump Cartoon

Calculating Work

work = w = external force x distance

(if the force is constant)

between
the system and
SURROUNDINGS

displacement
in the SYSTEM

The sign (+ or -) depends on whether system expands or contracts in response to the force.

What if the force is NOT constant? Calculus

$$\text{a very small amount of work} = dw = f_{ext}(x)dx$$

where *dw*, *dx* mean infinitesimally small (but we can think of this as just meaning really, really, really, small);

$f_{ext}(x)$ means the force is NOT CONSTANT, but is a "function of x", i.e., depends on x

Now just add up all the small bits:

$$w = \int_{x_1}^{x_2} f_{ext}(x)dx$$

Note that the integral sign is an S, standing for SUM

Constant Force Case:

$$w = f_{ext}\int_{x_1}^{x_2} dx = f_{ext}(x_2 - x_1) = f_{ext}\Delta x$$

Earth's gravity is a nearly constant force.

force = mass x acceleration = mg, where g= 9.8 ms^{-2} at the earth's surface

- If you hold 1 kg (2.2 lbs) you feel a force = 1 kg x 9.8 ms^{-2}
  = 9.8 kg m s^{-2} = 9.8 Newtons = **9.8 N**
- Work to raise this 1 meter = 9.8 kg m s^{-2} x 1 m = 9.8 kgm^2s^{-2}
  = **9.8 Joule = 9.8 J**

- Work for you to climb a 1000 m mountain (3300 ft) like Baldy:
  = 100 kg x 9.8 ms^{-2} x 1000 m ≈ 100 x 10 x 1000 = ≈ 10^6 J = 10^3 kJ
  dividing by 4.184 kJ per kcal gives: 250 kcal = ~2.5 slices of bread.

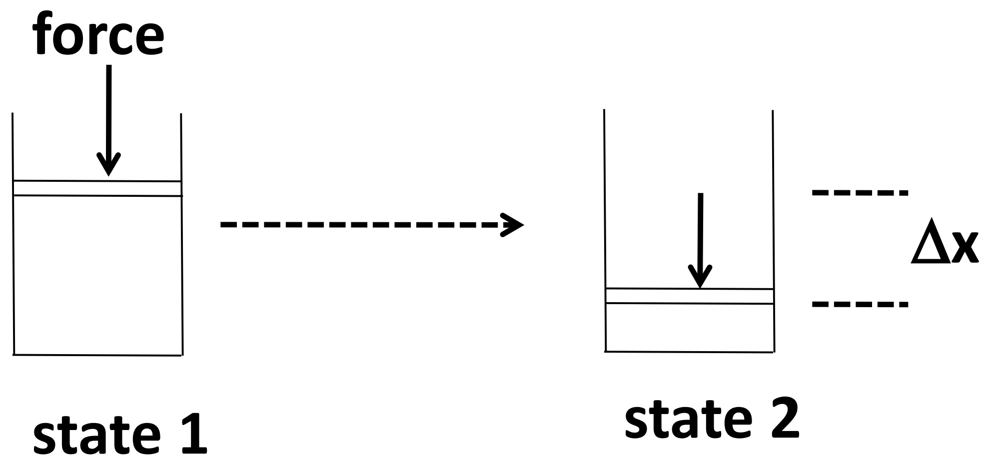
Doing "nothing", your body requires ~2000 kcal/day.

that is the equivalent of climbing 10,000* m, or 20 slices of bread!

*** Climbing Mt. Everest starting at sea level**

Expansion/Compression of System with Constant External Pressure

consider a **cylinder** filled with gas and capped with a piston



$$work = w = f_{ext}\Delta x$$

multiply top and bottom by Area of cylinder = A

$$w = \frac{f_{ext}}{A} A\Delta x = \text{pressure x volume} = P_{ext}\Delta V$$

but, what is the sign of w??

What is the sign??? ΔV is obviously negative and pressure is positive, but work is done ***on*** the system. Therefore, w is positive. The correct equation for this kind of work is: $w_{pv} = -p_{ext}\Delta V$

<u>ALWAYS TRUE</u>, for constant external pressure.

<u>SI unit of Pressure</u> **1 Nm^{-2} = 1 Pascal = 1 Pa**

Note: 1 Nm m^{-3} = 1 Jm^{-3} = 1 Pa also

1 bar = 1 x 10^5 Pa (the usual modern standard state)

1 atm = 1.013 x 10^5 Pa

1 liter = 1 L = 1x10^{-3} m^3 so:

1 L atm = 10^{-3} m^3 x 1.013 x 10^5 J m^{-3} = 101.3 J

1 L bar = 10^{-3} m^3 x 1.000 x 10^5 J m^{-3} = 100 J

Other common units of pressure

1 atm = 14.7 lbs/square inch

1 atm = **760 mm of mercury** = 760 torr = 29.9 inches Hg

This comes from the density of Hg, 13.6 g/cm^3

or 13.6 x 10^3 kg/m^3

and pressure = acceleration of gravity x density x height

$9.8\ ms^{-2} \times 13.6 \times 10^3\ kg\ m^{-3} \times 0.76\ m = 1.013 \times 10^5\ kg\ m^{-1}\ s^{-2}$

$= 1.013 \times 10^5\ (kg\ m\ s^{-2})m^{-2} = 1.013 \times 10^5\ Pa = 1\ atm$