**REVIEW: First Law in simple words and the main equation:**

Energy of the system + surroundings is conserved.

\[ \Delta U = q + w \]  
(eq. 2.26, p. 24)

- **\( \Delta U \)**: Energy change of system during process.
- **q**: Energy absorbed by system because of a temperature difference between system and surroundings. Something in the **SURROUNDINGS** must get colder or hotter, or else \( q = 0 \).
- **w**: Energy absorbed by system because of a **force acting** between system and surroundings. Something in the **SURROUNDINGS** must move against force (or the equivalent), or else \( w = 0 \).

**DISordered** energy

**ordered** energy

*DISordered* energy
**Isolated System** = Thermally **insulated** & No mechanical connection to surroundings

Weight lifter works out and the room heats up from 20° C to 25° C

Are $\Delta U$, $q$, $w$ positive, zero, or negative?

**Answers:** $\Delta U$, $q$, $w$ all = ZERO because **nothing is happening in the surroundings**
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 \( \Delta U \) is independent of path because initial and final states of system are same in both cases.
In old chemistry books and in most engineering texts one sees:

\[ \Delta U = q - w \]

Is this wrong?

What is the definition of \( w \) in this case?

\( w \) is defined as work obtained FROM the system if we use the above equation.
Relevance of $\Delta U = q + w$

If we choose to make a bonfire of our food
$\Delta U = q_{\text{max \ out}}$ and useful $w = 0$

If we choose to eat our food, the same reaction: food + Oxygen $\rightarrow$ CO$_2$ + H$_2$O
$\Delta U = q_{\text{min \ out}} + w_{\text{max \ out}}$

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

(BMR = basic metabolic rate)

Living things are able to get the maximum work from food. But typically not all of the energy can be turned to work.
Daily Energy Use
(75 kg man)

(BMR = basic metabolic rate)
Living things have evolved to get the most possible work from the $\Delta U$ from burning food.

**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$^+$**.
Calculating Work

work = w = external force \times 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

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:

\[
W = \int_{x_1}^{x_2} f_{ext}(x) \, dx
\]

**Constant Force Case:**

\[
W = f_{ext} \int_{x_1}^{x_2} dx = f_{ext}(x_2 - x_1) = f_{ext} \Delta x
\]

Note that the integral sign is an S, standing for **SUM**
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 kgm²s⁻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 = ≈ 10⁶ J = 10³ 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

![Diagram of cylinder with force and displacement](image)

work \( w = w = f_{ext} \Delta x \)

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: \( w_{pv} = -p_{ext}\Delta V \)

**ALWAYS TRUE, for constant external pressure.**

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**SI unit of Pressure**

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/cm³
or 13.6 x 10³ kg/m³
and pressure = acceleration of gravity x density x height

9.8 ms⁻² x 13.6 x 10³ kg m⁻³ x 0.76 m = 1.013 x 10⁵ kg m⁻¹ s⁻²

= 1.013 x 10⁵ (kg m s⁻²) m⁻² = 1.013 x 10⁵ Pa = 1 atm