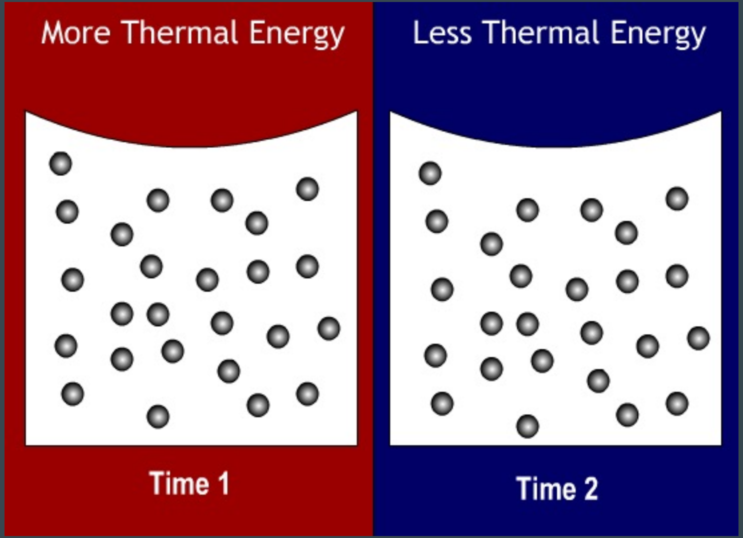

PHYS 2211 K

Week 9, Lecture 2

2022/03/10

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6 clicker questions today

On today's class…

1. Power
2. Thermal energy
3. Heat

CLICKER 1: Favorite Queen of Arendelle

A. Iduna

B. Elsa

C. Anna

Energy stuff

- Energy principle $\Delta E_{\text{sys}} = W_{\text{surr}} + Q$
- Work $W = \vec{F} \cdot d\vec{r}$
- Energies

$$\Delta K = \frac{1}{2}mv^2 \qquad \Delta U_g = mg\Delta y \qquad \Delta U_g = -\frac{GMm}{r}$$

$$\Delta U_e = \frac{k_e Q q}{r} \qquad \Delta U_s = \frac{1}{2}ks^2$$

Power

- Notice that time is never involved anywhere in the energy principle

$$\Delta E_{\text{sys}} = W_{\text{surr}} + Q$$

- The left side only cares about initial and final states, and the right side only cares about total displacement and changes due to temperature differences

- To determine the rate at which energy is being transferred into or out of the system we need a new concept: power

Power

- Power is the rate of change of energy transfer over time

- Units: Joules / second = Watt

- Careful: don't confuse "W" for Watt and "W" for work!

We don’t have enough letters...

A = Ampere, area
B = magnetic field
C = heat capacity, Coulomb, capacitance
D = displ. current
E = electric field, energy, exa-
F = force, Farad
G = grav. const.
H = Henry, Hubble constant
I = electric current, moment of inertia
J = current density, Joule
K = kinetic energy, Kelvin

L = Lagrangian, angular momentum
M = big mass, mega-
N = Newton, normal force, North
O = origin
P = power, pressure
Q = heat
R = resistance
S = entropy, South
T = temperature
U = potential energy
V = Volt, voltage
W = Watt, work
X = elect. reactance
Y = Young’s modulus, Bessel functions
Z = atomic number

a = acceleration, semi-major axis
b = impact param., semi-minor axis
c = speed of light
d = distance, diameter
e = fund. charge
f = friction, freq.
g = accel. of gravity
h = height, Planck constant
i = sqrt(-1), i-hat
j = j-hat
k = spring stiffness, Boltzmann const., electric constant, k-hat, kilo-

l = quantum angular momentum
m = mass, meter
n = refraction index
o = looks like zero
p = momentum
q = electric charge
r = radius, r-vector
s = spring stretch, seconds
t = time
u = atomic mass unit
v = velocity
w = width
x = x-hat
y = y-hat
z = z-hat, redshift

Greek letters are all used too…

α = alpha = fine structure constant, angular acceleration, alpha radiation
β = beta = beta radiation
Γ, γ = gamma = Gamma function, gamma radiation, relativistic correction
Δ, δ = delta = change, infinitesimal change, Dirac delta function
ε = epsilon = permittivity, small perturbation
ζ = zeta = Riemann zeta function
η = eta = efficiency
θ = theta = angle
ι = iota = looks like i
κ = kappa = looks like k
Λ, λ = lambda = cosmological constant, wavelength, eigenvalue, linear density

μ = mu = coefficient of friction, micro-
ν = nu = frequency
ξ = xi = initial mass function, correlation function, "squiggle"
ο = omicron = looks like zero
Π, π = pi = product, pi
ρ = rho = volume density, resistivity
Σ, σ = sigma = summation, accuracy of measurement, area density
τ = tau = torque
υ = upsilon = looks like u
ϕ, φ = phi = angle
χ = chi = chi-square statistic
Ψ, ψ = psi = wave function
Ω, ω = omega = Ohm, angular velocity

Example: How much energy is needed to power a 60 W light bulb for eight hours?

CLICKER 2: How much power does it take to accelerate a car that has mass $m = 1500$ kg from 0 to 100 km/hr in 3 seconds?

A. $P = 409$ kW

B. $P = 2.5$ MW

C. $P = 193$ kW

D. $P = 1.47$ MW

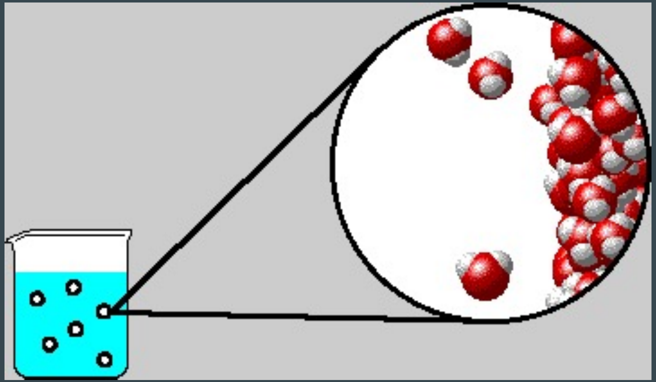
reminder:

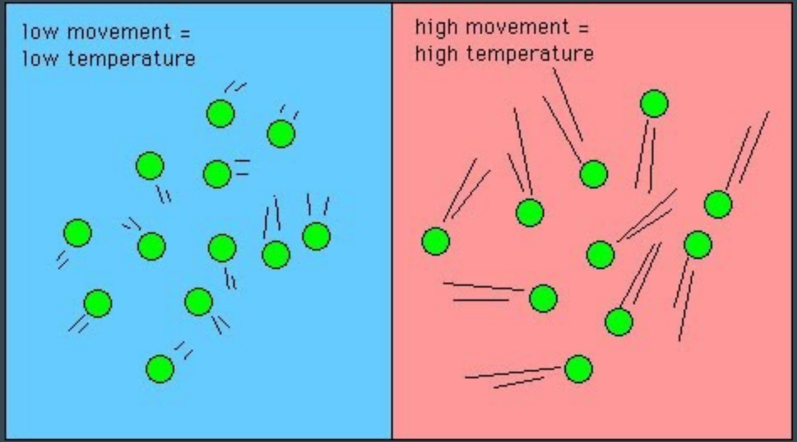
"kilo" = k = 10^3

"mega" = M = 10^6

Temperature

- Temperature is a measure of the average kinetic energy of the atoms/molecules that make up the system
- Kinetic energy of each atom is not easily measurable, so we use temperature of the system as proxy
- Higher temperature means higher kinetic energy for the particles





Thermal Energy

- Energy associated with the temperature of the system

(the "mcat" equation, b/c Δ looks like A)

$$\underbrace{\Delta E_{\mathrm{th}}}_{\text{change in thermal energy of the system}} = \underbrace{m}_{\text{mass of the system (in GRAMS, not kg)}}\underbrace{C}_{\text{specific heat of the system}}\underbrace{\Delta T}_{\text{change in temperature of the system}}$$

change in thermal energy of the system

mass of the system (in **GRAMS**, not kg)

specific heat of the system

units: $\frac{J}{g\ {}^\circ C}$

change in temperature of the system

- This is a type of internal (microscopic) energy

Units warning!

- Specific heat includes **GRAMS**, not KILOGRAMS, so the mass of the system needs to be expressed in grams too

- Specific heat includes degrees Celsius. Since a degree Celsius is the same size as a Kelvin, the units of specific heat can be expressed with Kelvin as well and it would be equivalent

$$\frac{J}{g\ {}^\circ C} \Leftrightarrow \frac{J}{g\ K}$$

"Kelvin"
(not kinetic energy)

- A degree Fahrenheit is smaller than a degree Celsius, so you CANNOT use Fahrenheit temperatures unless you convert the units

CLICKER 3: Olaf is a 15 kg snowman whose temperature went suddenly from -6°C to 20°C. What was the change in thermal energy of Olaf? The specific heat of water is C = 4.186 J/(g °C)

A. 8.79×10^2 J

B. 1.63×10^3 J

C. 8.79×10^5 J

D. 1.63×10^6 J

Heat (Q)

- Transfer of energy between system and surroundings due to a difference in temperature

- Goes on the right side of the energy principle:

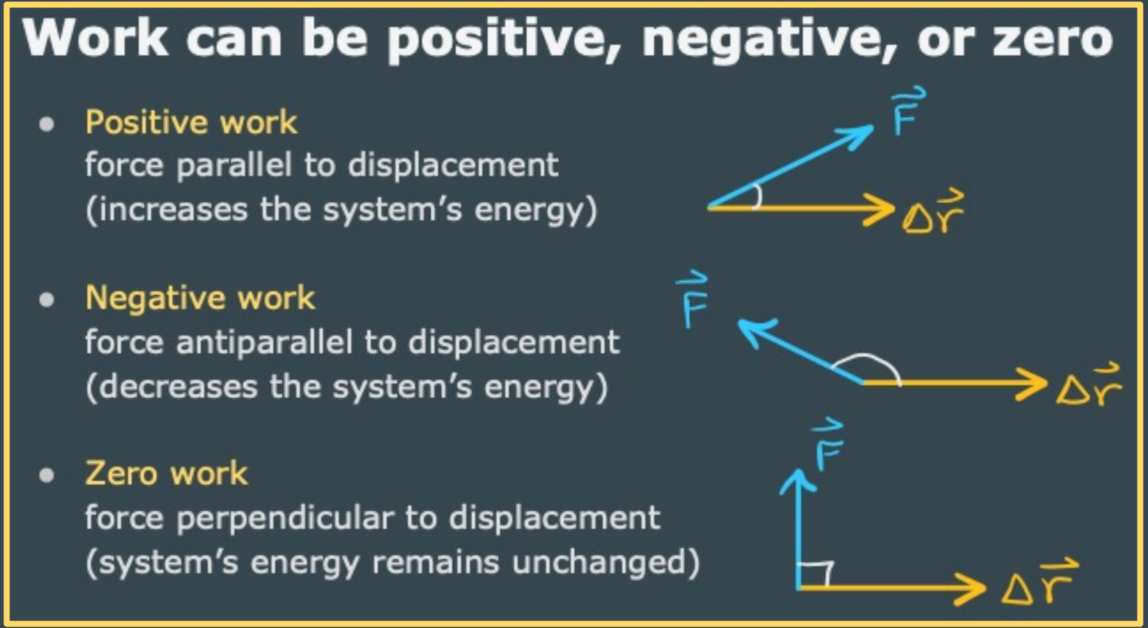
$$\Delta E_{\text{system}} = W + Q$$

- Can be thought of as microscopic work!

Remember this slide? (2/24)

When it comes to changing the energy of the system, heat behaves the same way as work:

- $Q > 0$ adds energy to the system
- $Q < 0$ removes energy from the system
- $Q = 0$ doesn't change the energy of the system



CLICKER 4: Which of the following statements is correct?

A. Q and ΔE_{th} are the same thing

B. Q and ΔE_{th} are not the same, but they are always equal to each other

C. ΔE_{th} can be nonzero even if Q is zero

D. ΔE_{th} is always positive

Open and Closed Systems

- If $W = 0$ (isolated) and $Q = 0$ (insulated), then the system is closed
  - There are no transfers of energy between system and surroundings
  - The energy of the system is constant, $\Delta E = 0$

- If there's nonzero W or Q, then the system is open
  - Energy can be transferred between the system and the surroundings
  - The energy of the system is not constant, $\Delta E \neq 0$

Example: Café con leche – An insulated cup contains 350 grams of coffee at 95°C. The person holding the cup of coffee prefers to drink it at 82°C, so they decide to add cold milk (temperature 5°C) to the cup. How many grams of milk need to be added to the cup to get the desired temperature?

The specific heat of coffee is 4.2 J/(g °C) and for milk it's 3.9 J/(g °C).

System:

Initial state:

Surroundings:

Final state:

Energy Principle:

Example: Café con leche – An insulated cup contains 350 grams of coffee at 95°C. The person holding the cup of coffee prefers to drink it at 82°C, so they decide to add cold milk (temperature 5°C) to the cup. How many grams of milk need to be added to the cup to get the desired temperature? The specific heat of coffee is 4.2 J/(g °C) and for milk it's 3.9 J/(g °C).

$$\Delta E_{\mathrm{th1}} + \Delta E_{\mathrm{th2}} = 0$$

Coffee	Milk
m_1 = 350 g	m_2 = ??? g
C_1 = 4.2 J/(g°C)	C_2 = 3.9 J/(g°C)
T_{1i} = 95 °C	T_{2i} = 5 °C

CLICKER 5: You pour 200 grams of hot coffee (95°C) into a non-insulated cup, then sit down to browse reddit for "a little while". Next thing you know, the coffee is now at room temperature (25°C). What was the transfer of energy (Q) between system (coffee) and surroundings? The specific heat of coffee is 4.2 J/(g °C).

A. -58800 J

B. 0 J

C. 58800 J

Example: One can of Coke at room temperature (25°C) has 371 g of liquid and a specific heat of 0.85 J/(g °C). You put the Coke in the fridge, which has a power of 200 W. Assuming that all the energy goes into cooling this one can of Coke, how much time does it take for its temperature to reach 2°C? Is this a realistic answer?

CLICKER 6: You take a bath in a tub that has 200 L of water. Water has density 1000 g/L and specific heat 4.2 J/(g°C). By the time you finish bathing, the water has reached thermal equilibrium with your body (37°C). You remember the energy principle and wonder if you can increase the temperature of the water by stirring it with your arms, doing work at a rate of 300 J/s. How many minutes would you need to stir to increase the temperature by 1°C?

A. 46.7 min

B. 103.6 min

C. 1726 min (28.8 hr)

D. 2800 min (46.7 hr)

Solution: You take a bath in a tub that has 200 L of water. Water has density 1000 g/L and specific heat 4.2 J/(g°C). By the time you finish bathing, the water has reached thermal equilibrium with your body (37°C). You remember the energy principle and wonder if you can increase the temperature of the water by stirring it with your arms, doing work at a rate of 300 J/s. How many minutes would you need to stir to increase the temperature by 1°C?