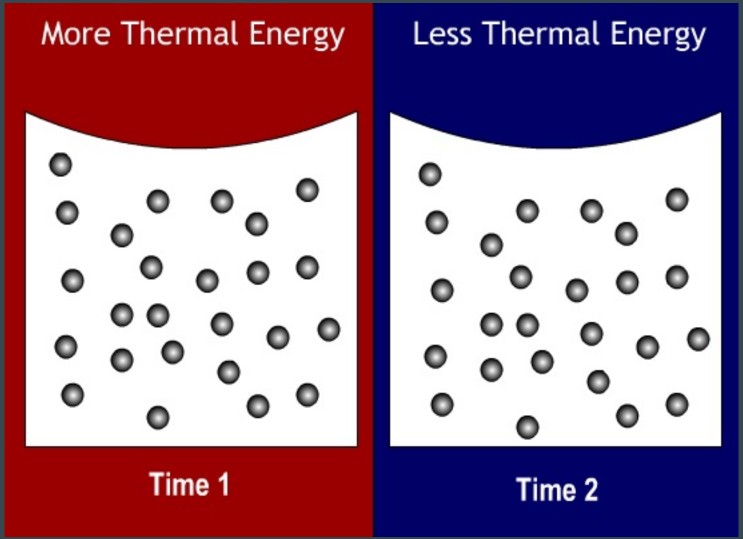


PHYS 2211 K

Week 9, Lecture 2

2022/03/10

Dr Alicea (ealicea@gatech.edu)

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

$$\Delta E = W + Q$$

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

$$P = \frac{\Delta E}{\Delta t} = \frac{W}{\Delta t} = \frac{\vec{F} \cdot \Delta \vec{r}}{\Delta t} = \vec{F} \cdot \vec{v}$$

$(\text{if } Q = 0)$

$\vec{v}$

- Units: Joules / second = Watt

$$W = \frac{J}{s} = \frac{Nm}{s} = \frac{kg\,m}{s^2}\frac{m}{s} = \frac{kg\,m^2}{s^3}$$

- 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**?

$$P = \frac{\Delta E}{\Delta t} \Rightarrow \Delta E = P\Delta t$$

$$\frac{8\,\cancel{hr}}{} \left| \frac{60\,\cancel{min}}{1\,\cancel{hr}} \right| \frac{60\,sec}{1\,\cancel{min}} = 28800\ sec$$

$$\Delta E = (28800\,\cancel{s})\left(60\,\frac{J}{\cancel{s}}\right) = \boxed{1.728 \times 10^{6}\ J}$$

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

$$\frac{100\ \cancel{km}}{\cancel{hr}}\cdot\frac{1000\,m}{1\ \cancel{km}}\cdot\frac{1\ \cancel{hr}}{60\ \cancel{min}}\cdot\frac{1\ \cancel{min}}{60\ sec} = \frac{(100)(1000)}{(60)(60)} = 27.8\ m/s$$

$$\Delta E = \Delta K = \frac{1}{2}m\left(v_f^2 - v_i^2\right) =$$

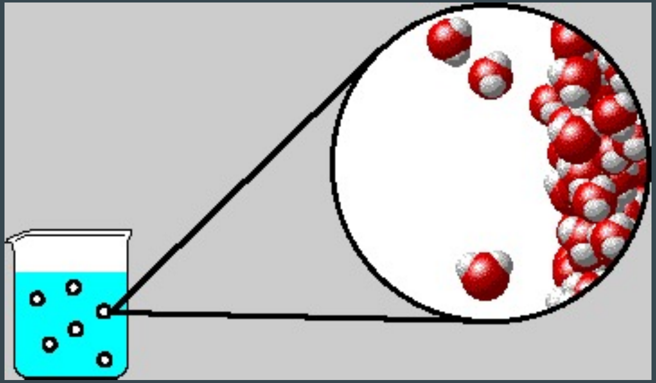
$$= \left(\frac{1}{2}\right)(1500)\left(27.8^2 - \cancel{0^2}\right) = 579630\ J$$

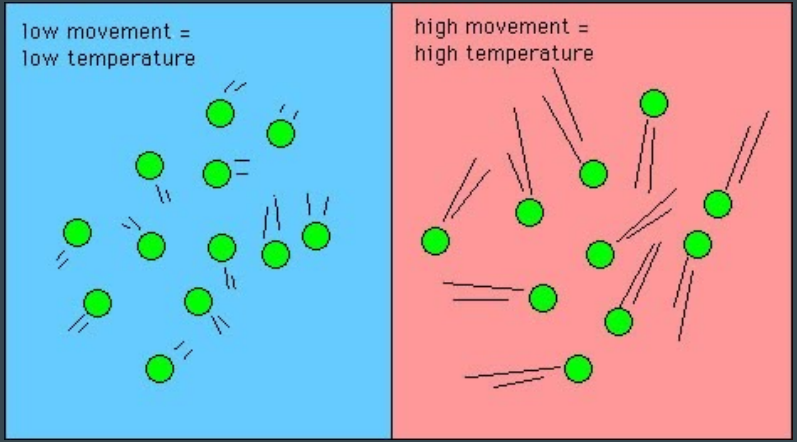
$$P = \frac{\Delta E}{\Delta t} = \frac{579630\ J}{3\ sec} =$$

$$= 193210\ J/s = \boxed{193\ kW}$$

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)

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

units: $\dfrac{J}{g\,^{\circ}C}$

- 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

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

"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

$$\Delta E = mC\Delta T =$$

$$= (15000\cancel{g})\left(4.186 \frac{J}{\cancel{g}\,\cancel{°C}}\right)\left(20\cancel{°C} - (-6)\cancel{°C}\right) =$$

$$= \boxed{1.63 \times 10^6 \text{ J}}$$

Heat (Q)

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

- Goes on the right side of the energy principle:

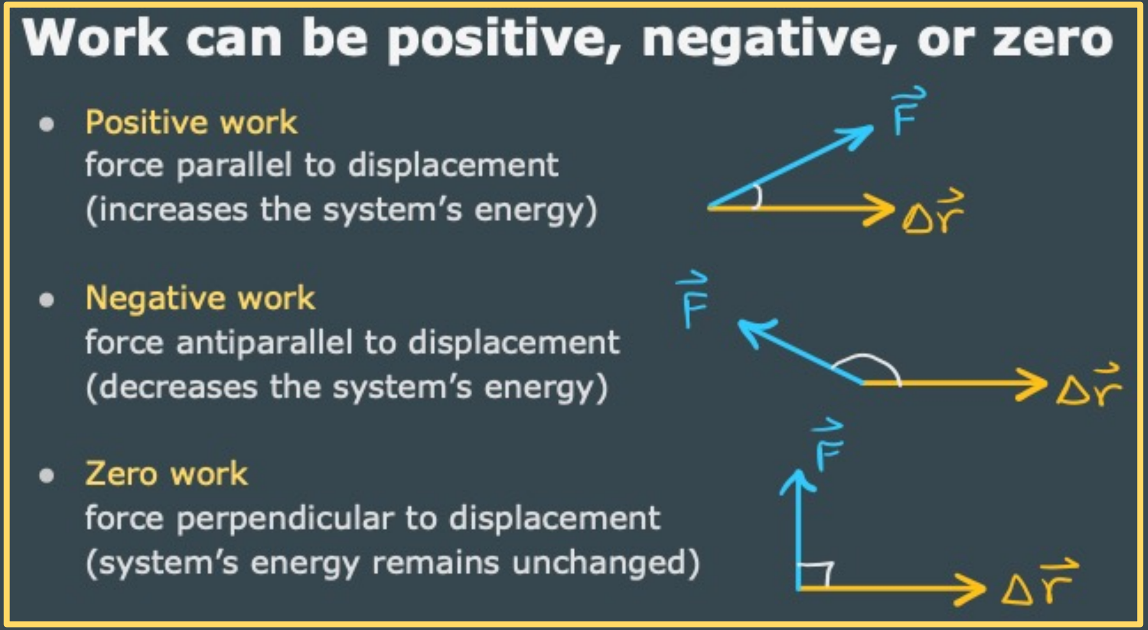
$$\Delta E_{\text{system}} = W + Q$$

- 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

$$* \Delta E_{th} = W + Q$$

if $Q = 0$, $\Delta E_{th} = W$

if $W = 0$, $\Delta E_{th} = Q$

$$\Delta E_{th} = mc\Delta T = mc(T_f - T_i)$$

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: coffee + milk

Initial state: coffee @ 95°C
milk @ 5°C

Surroundings: $Q = 0$
$W = 0$

Final state: coffee + milk @ 82°C

Energy Principle:

$$\Delta E = \cancel{W}^{0} + \cancel{Q}^{0}$$

$$\Delta E_{th,\,coffee} + \Delta E_{th,\,milk} = 0$$

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).

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

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

$$T_{f1} = T_{f2} = T_f = 82°C$$

$$m_1 C_1 \Delta T_1 + m_2 C_2 \Delta T_2 = 0$$

$$m_1 C_1 (T_f - T_{1i}) + m_2 C_2 (T_f - T_{2i}) = 0$$

$$m_2 C_2 (T_f - T_{2i}) = -m_1 c_1 (T_f - T_{1i})$$

$$m_2 = \frac{-m_1 C_1 (T_f - T_{1i})}{C_2 (T_f - T_{2i})} = \frac{-(350g)(4.2 \frac{\cancel{J}}{\cancel{g°C}})(82\cancel{°C} - 95\cancel{°C})}{(3.9 \frac{\cancel{J}}{\cancel{g°C}})(82\cancel{°C} - 5\cancel{°C})} = \boxed{63.6 g}$$

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

$$\Delta E = \cancel{W}_{0} + Q$$

$$\Delta E_{th} = Q$$

$$Q = m C \Delta T = (200)(4.2)(25-95) =$$

$$= \boxed{-58800 \text{ J}}$$

energy was removed from the system

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?

$$\Delta E = \cancel{W}^{\,0} + Q$$

$$P = \frac{\Delta E}{\Delta t} = \frac{Q}{\Delta t}$$

$$\Rightarrow Q = P\Delta t$$

$$mC\Delta T = P\Delta t$$

$$\Delta t = \frac{mC\Delta T}{P} = \left|\frac{(371)(0{,}85)(2-25)}{200}\right| = \boxed{36.3 \text{ sec}}$$

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?

$V = 200\,L$

$\rho = 1000\,g/L$

$$\rho = \frac{m}{V} \Rightarrow m = \rho V = (200\,\cancel{L})(1000\,g/\cancel{L}) = 200\,000\,g$$

$$P = 300\,\frac{J}{s} = \frac{W}{\Delta t}$$

$$\Delta E = W + \cancel{Q}\,0$$

$$\Delta t = \frac{W}{P}$$

$$mc\Delta T = P\Delta t$$

$$\Delta t = \frac{mc\Delta T}{P} = \frac{(200\,000)(4.2)(1)}{300} = 2800\ \text{sec}$$

$$= \boxed{46.7\,\text{min}}$$