Energy Transfer and Heat!

Extra Practice: 11.1, 11.3, 11.5, 11.7, 11.9, 11.15, 11.17, 11.25, 11.27, 11.33

Movie Assignment Grading Update

Your grades will be posted today or this weekend.

(Feedback may already be embedded in your submitted draft document; view on eCampus)

- Specific heat
- Latent heat
- Methods of heat transfer

Applications:
Fire-eating!
Fire extinguishers!
The physics of tin foil!
Weight loss!
Reminder: Last Lecture

Put two things in thermal contact. Energy will flow from the hotter to colder object. (Until they reach thermal equilibrium)

How do we define heat?

Heat \( (Q) \) = A measure of energy TRANSFER.

“Heat is the transfer of energy between a system and its environment due to a temperature difference between them”

Some things are hard to make hotter.

(it takes more energy to get them hot)

Changing temperature \( \Delta T \)

\[ Q = m c \Delta T \] Energy transfer
This equation is valid as long as there is no change in state of the material, e.g., solid to liquid.

\[
Q = mc\Delta T
\]

Energy required To change temperature

Makes fixed amounts of energy per time.

I cooked one hot dog for 10 seconds, and it heated up by 2°C. What should I do if I want to heat up three hotdogs by 2°C? Assume that all the energy created by the microwave goes into the hotdogs.

A. Cook them the same amount of time.
B. Cook them three times as long.
C. Cook them 1/3 as long.
D. Cook them six times as long.

Converting energy to temperature

\[
Q = mc\Delta T
\]

Units of Q:

Joules

[Historically, calories: 4194 Joules = 1 kilocalorie = 1 Calorie (on nutrition labels)]

(Nutrition Facts)
Converting energy to temperature

Units of c:

\[ Q = m \cdot c \cdot \Delta T \]

J / (kg K)
or
J / (kg °C)

Specific heat for several materials:

- \( c_{\text{mercury}} = 138 \text{ J/(kg K)} \) – very easy to heat (thermometers)
- \( c_{\text{ice}} = 2090 \text{ J/(kg K)} \)
- \( c_{\text{ethanol}} = 2428 \text{ J/(kg K)} \) – much easier than water
- \( c_{\text{water}} = 4184 \text{ J/(kg K)} \) – very difficult to heat

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Converting Kinetic Energy to Heat

A 2000 kg car traveling at 20 m/s crashes into a tree. If half of the kinetic energy of the car is transferred into heat and that energy is absorbed by the car bumper, by how much is the temperature of the bumper temporarily increased?

Let’s say a bumper weighs 15kg.
c for bumper plastic is \( \sim 1800 \text{ J/(kg K)} \)

\[ Q = m \cdot c \cdot \Delta T \]

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\[ Q = m \cdot c \cdot \Delta T \]

What is the change in temperature if the 2x10^3 J instead went into heating a 15kg chromium car hood, \( c = 460 \text{ J/(kg K)} \)?

A. 0.22 °C
B. 7.4 °C
C. 29 °C
D. 4985 °C
Phase changes (e.g. solid to liquid)

\[ Q = m \cdot c \cdot \Delta T \]

NO LONGER APPLIES if something melts/boils/condenses!

at phase transition, need extra energy; use substance’s latent heat, \( L \):

\[ Q = \pm m \cdot L \]

Applying constant heat per second to water:

Temperature (°C)

\[ \text{Ice} \quad m_{l_1} \quad \text{Water} \]

Time (keep adding energy with time)

Energy (\( Q \)) required for phase change

“Fusion”

Latent heat of fusion (\( L_{m} \))
- solid <-> liquid
- melting or freezing
- \( Q = \pm m_{l_1} \)

“Vaporization”

Latent heat of vaporization (\( L_{v} \))
- liquid <-> gas
- boiling or condensing
- \( Q = \pm m_{l_v} \)

“Sublimation”

Latent heat of sublimation (\( L_{s} \))
- solid <-> gas (rare)
- Example: fuming of dry ice
- \( Q = m_{l_s} \)

Pick sign such that hotter objects have more energy (adding to or taking away energy through the phase change)

How much energy is required to change a 40-g ice cube from ice at -10°C to water at 50°C?

How many terms of \( m \cdot c \cdot \Delta T \) and/or \( m \cdot L \) will we have?

Heating a substance within single state:

\[ Q = m \cdot c \cdot \Delta T \]

Extra energy to change state:

\[ Q = \pm m \cdot L \]
Methods of energy transport.

1) Conduction

- **DIRECT TOUCH**: passing on vibrations directly.
- Things “FEEL HOTTER” with greater conduction!
- Rate of energy transfer ($P=\text{power}$) depends on:
  - Temperature difference ($T_H-T_C$)
  - Area of contact ($A$)
  - Thickness of material ($L$)
  - Thermal conductivity of the material ($k$)
    - $k_{\text{brass}}=385 \text{ W/(m}\cdot\text{K})$ good conductor
    - $k_{\text{alu}}=0.028 \text{ W/(m}\cdot\text{K})$ good insulator
    - Higher $k$ means more heat flow

\[
P = \frac{Q}{\Delta t} = kA \frac{T_H-T_C}{L} \quad \text{[not on test, just here to demonstrate]}
\]

2) Convection

- Migrating (hot) fluids (air, water).
- **HOT AIR RISES** (why?).
- Hotter air/fluid: less density ($\rho=m/V$) of the air decreases, and it rises due to a buoyant force
3) Radiation

- ALL OBJECTS RADIATE LIGHT! (at some wavelength! Many things on Earth: infrared.)
- No touch required.

Common examples...

Heat loss/gain from your house is mostly from radiation.

Foil keeps food warm by blocking passage of radiation, and by containing hot air.

Don’t put it by something cold (conduction will take energy away through touch).
The best insulator!

Foil: reflects back radiation, prevents convection if sealed.
Foam: prevents conduction.


Food (energy in)

Heat (percentage of energy lost to body, heat depends on metabolism)

Work (W = ΔKE + ΔPE)
i.e. movement and exercise
(or stored as fat)

4194 Joules
1 kilocalorie
1 Calorie
(on nutrition labels)
About how many Joules do I have available?

Standard metabolism: ~70% to heat.
(~30% residual in body)

Higher metabolism: food mostly goes to heat!
So you’ll need to expend less mechanical energy (less exercise) to work it off!
Challenge to you.

Think of your winter coat. What principles does it use to keep you warm?