TABLE 11.1 Specific Heats of Some Materials at Atmospheric Pressure

Substance	J/kg·°C	cal/g·°C
Aluminum	900	0.215
Beryllium	1 820	0.436
Cadmium	230	0.055
Copper	387	0.092 4
Germanium	322	0.077
Glass	837	0.200
Gold	129	0.030 8
Ice	2 090	0.500
Iron	448	0.107
Lead	128	0.030 5
Mercury	138	0.033
Silicon	703	0.168
Silver	234	0.056
Steam	2 010	0.480
Water	4 186	1.00

Example

A 1 kg block of Copper is raised in temperature by 10 °C. What was the heat transfer Q.?

Answer:

$Q=cm\Delta T$

$=387*1*10=3870$ J

1 cal = 4.186 J

Q=924.5 cal

Another one

A block of Copper is dropped from a height of 10 m. Assuming that all the potential energy is transferred into internal energy (heat) when it hits the ground, what is the raise in temperature of the block (c_{copper}=387 J/(kg ^oC))?

Potential energy: mgh=10 mg J

All transferred into heat Q: $Q = cm\Delta T$

$10mg = 387m\Delta T$

$\Delta T = 10\ g/387 = 0.25\ ^oC$

An example

The contents of a can of soda (0.33 kg) which is cooled to 4 ^oC is poured into a glass (0.1 kg) that is at room temperature (20 ^0C). What will the temperature of the filled glass be after it has reached full equilibrium (glass and liquid have the same temperature)?

Given c_{water}=4186 J/(kg ^oC) and c_{glass}=837 J/(kg ^0C)

$$Q_{cold} = -Q_{hot}$$

$$m_{water} c_{water} (T_{final} - T_{water}) = -m_{glass} c_{glass} (T_{final} - T_{glass})$$

$$T_{final} = \frac{m_{water} c_{water} T_{water} + m_{glass} c_{glass} T_{glass}}{m_{water} c_{water} + m_{glass} c_{glass}}$$

= (0.33*4186*4+0.1*837*20)/(0.33*4186+0.1*837)=

= 4.9 ^oC

And another

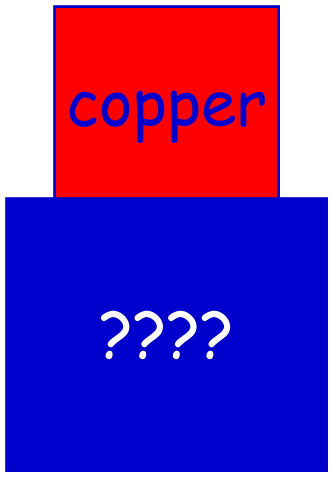
A block of unknown substance with a mass of 8 kg, initially at T=280 K is thermally connect to a block of copper (5 kg) that is at T=320 K (c_{copper}=0.093 cal/g ^{0}C). After the system has reached thermal equilibrium the temperature T equals 290 K. What is the specific heat of the unknown material in cal/g ^{o}C?

$$Q_{cold} = -Q_{hot}$$

$$m_{unknown} c_{unknown} (T_{final} - T_{unknown}) = -m_{copper} c_{copper} (T_{final} - T_{copper})$$

$$c_{unknown} = \frac{-m_{copper} c_{copper} (T_{final} - T_{copper})}{m_{unknown} (T_{final} - T_{unknown})}$$

$$c_{unkown} = \frac{-5000 \cdot 0.093 \cdot (290-320)}{8000 \cdot (290-280)} = 0.17 \text{ cal/g } ^oC$$



Heating water with a ball of Lead

A ball of Lead at T=100 °C with mass 300 g is dropped in a glass of water (0.3 L) at T=20 °C. What is the final (after thermal equilibrium has occurred) temperature of the system? (c_{water}=1 cal/g °C, c_{lead}=0.03 cal/g °C $\rho_{water}=10^3$ kg/m^3)

$$Q_{cold}=-Q_{hot}$$

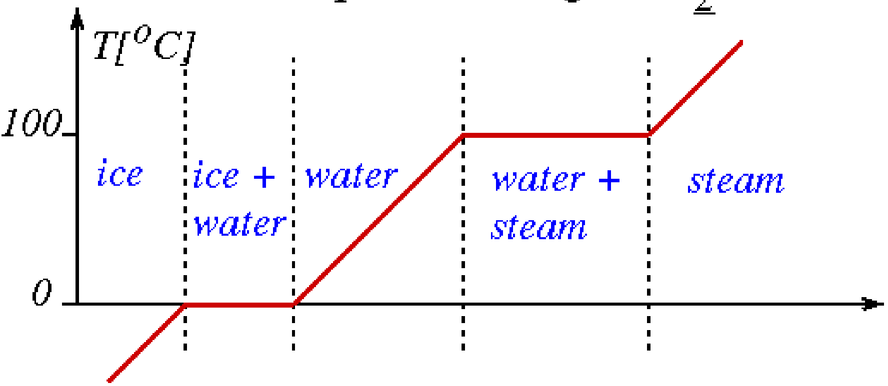
$$m_{water}c_{water}(T_{final}-T_{water})=-m_{lead}c_{lead}(T_{final}-T_{lead})$$

$$T_{final}=\frac{m_{water}c_{water}T_{water}+m_{lead}c_{lead}T_{lead}}{m_{water}c_{water}+m_{lead}c_{lead}}$$

= (0.3*1*20+0.3*0.03*100)/(0.3*1+0.3*0.03)=

= 6.9/0.309=22.3°C

Example: Heating of H_2O



(a)	ice	$Q = m\, c_{ice} \Delta T$	raises T of ice
(b)	ice+water	$Q = m\, L_f$	melts ice
(c)	water	$Q = m\, c_{water} \Delta T$	raises T of water
(d)	water + steam	$Q = m\, L_v$	vaporizes water
(e)	steam	$Q = m\, c_{steam} \Delta T$	raises T of steam

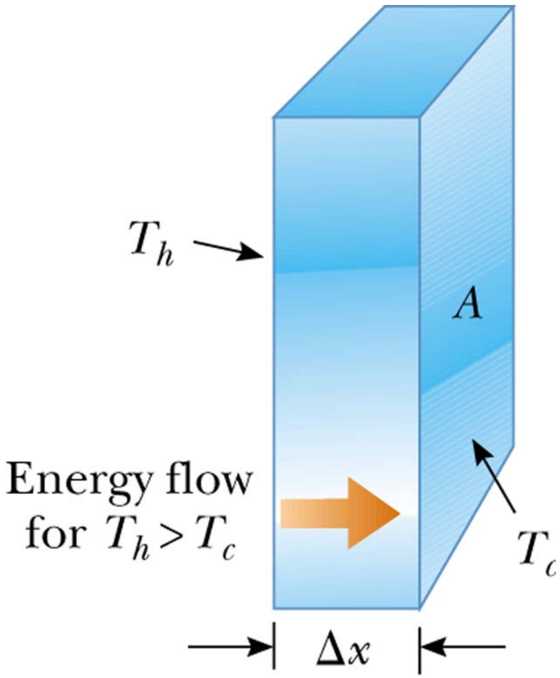
A) Ice from -30 to 0 °C
B) Ice to water
C) water from 0 °C to 100 °C
D) water to steam
E) steam from 100 °C to 150 °C
TOTAL

Ice with T=-30 °C is heated to steam of T=150 °C. How many heat (in cal) has been added in total?

c_{ice}=0.5 cal/g °C
c_{water}=1.0 cal/g °C
c_{steam}=0.480 cal/g °C
L_f=540 cal/g
L_v=79.7 cal/g
m=1 kg=1000g

Q=1000*0.5*30= 15000 cal
Q=1000*540= 540000 cal
Q=1000*1.0*100=100000 cal
Q=1000*79.7= 79700 cal
Q=1000*0.48*50=24000 cal

Q= =758700 cal



Example

A glass window ($A=4\ m^2$, $\Delta x=0.5$ cm) separates a living room ($T=20\ ^0C$) from the outside ($T=0\ ^oC$). A) What is the rate of heat transfer through the window ($k_{glass}=0.84\ J/(m.s.^oC)$)? B) By what fraction does it change if the surface becomes 2x smaller and the temperature drops to $-20\ ^0C$?

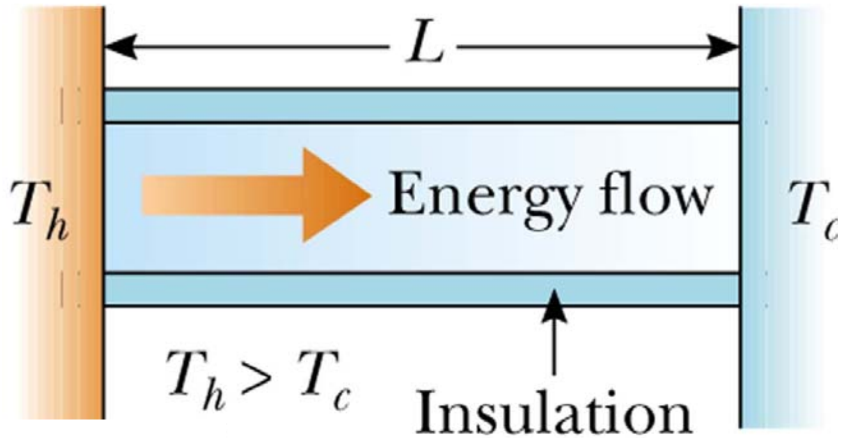
A) $P=kA\Delta T/\Delta x=0.84*4*20/0.005=13440$ Watt

B) $P_{orig}=kA\Delta T/\Delta x$ $P_{new}=k(0.5A)(2\Delta T)/\Delta x=P_{orig}$

The heat transfer is the same

Another one.

Heat reservoir



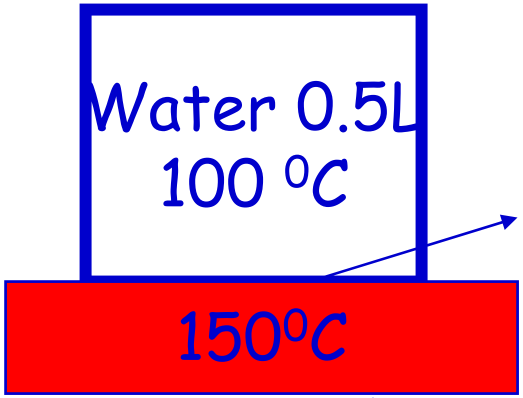
Heat sink

An insulated gold wire (i.e. no heat lost to the air) is at one end connected to a heat reservoir (T=100 ^{0}C) and at the other end connected to a heat sink (T=20 ^{0}C). If its length is 1m and P=200 W what is its cross section (A)?

k_{gold}=314 J/(m.s.^{0}C).

$P=kA\Delta T/\Delta x=$314*A*80/1=25120*A=200

A=8.0E-03 m^2



And another

A=0.03 m^2 thickness: 0.5 cm.

A student working for his exam feels hungry and starts boiling water (0.5L) for some noodles. He leaves the kitchen when the water just boils.The stove's temperature is 150 ^{0}C. The pan's bottom has dimensions given above. Working hard on the exam, he only comes back after half an hour. Is there still water in the pan? (L_v=540 cal/g, k_{pan}=1 cal/(m.s.^{0}C)

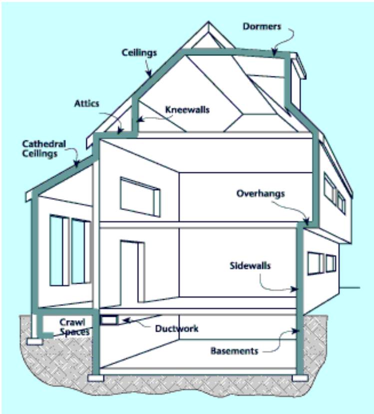
To boil away 0.5L (=500 g) of water: $Q=L_v*500=270000$ cal

Heat added by the stove: $P=kA\Delta T/\Delta x=1*0.03*50/0.005=$

$=300$ cal

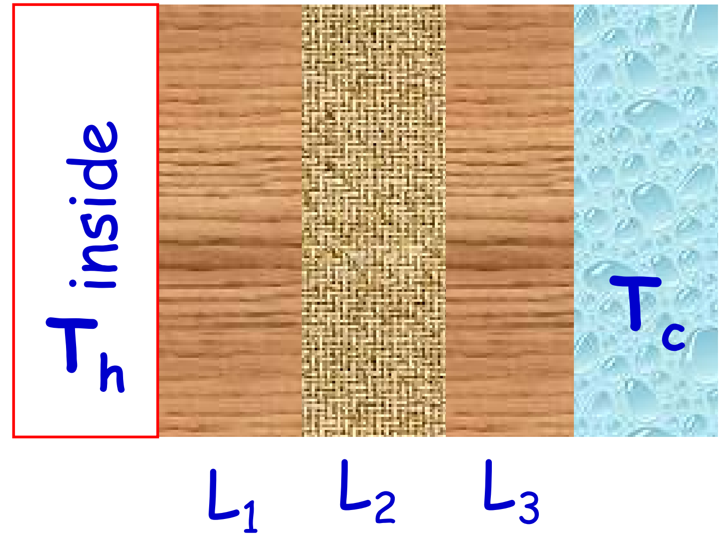
$P=Q/\Delta t$ $\Delta t=Q/P=270000/300=900$ s (15 minutes)

He'll be hungry for a bit longer…



Isolation

$$P = \frac{Q}{\Delta t} = \frac{A(T_h - T_c)}{\sum_i (L_i / k_i)}$$



A house is built with 10 cm thick wooden walls and roofs. The owner decides to install insulation. After installation the walls and roof are 4 cm wood+2 cm isolation+4 cm wood. If k_{wood}=0.10 J/(m.s.^{0}C) and $k_{isolation}$=0.02 J/(m.s.^{0}C), by what factor does he reduce his heating bill?

$P_{before}=A\Delta T/[0.10/0.10]=A\Delta T$
$P_{after}=A\Delta T/[0.04/0.10+0.02/0.02+0.04/0.10]=0.55A\Delta T$
Almost a factor of 2 (1.81)!