Recap:Boiling

- We have discussed how **evaporation** takes place at a liquid's **"free" surface** at any **temperature**.
- Under special circumstances it can also occur **throughout** the body of liquid… called **boiling**.
- **Definition of boiling:**

❖ Any liquid will boil at a **given temperature** when its saturated vapor pressure **equals** surrounding atmospheric pressure.

Example water vapor pressures:

At 0 ºC water vapor pressure	= 0.006 Atm
60 ºC	= 0.2 Atm
100 ºC	= 1.0 Atm

- **At boiling:** Tiny pockets of **vapor** generated at any **point within liquid** have a **lower density** and than surrounding medium **creating small spheres of vapor.**

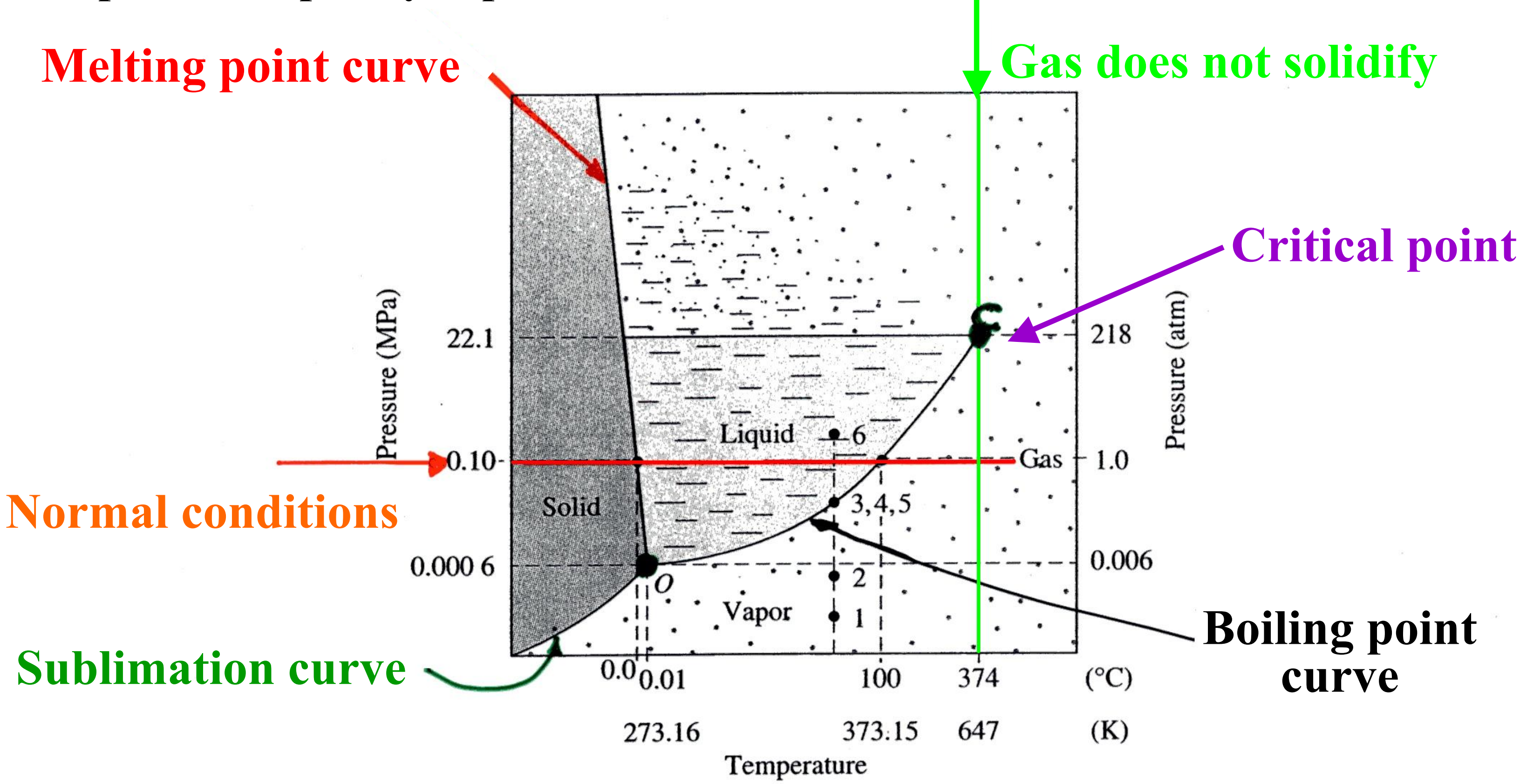
Boiling (cont'd)

- Feeding further heat will **cause boiling** to continue **without** changing liquid's **temperature**.
- **Steam** therefore has a **lot of energy** (~2.2 MJ /kg) and can be used to **transfer heat** from a boiler to a radiator where it is given up by **condensing** back (as latent heat) to liquid.

Summary:

- **Boiling point** therefore depends on **external pressure**. At **lower pressure** vapor bubbles can form **more easily** etc.
- Mount Everest (9 km) pressure = 0.4 Atm and $T_{boiling}$ = 74 ºC.
- Water is boiled off milk **at low pressure** without cooking it.
- **Pressure cooker** raises $T_{boiling}$ to typically 121 ºC (+1 Atmos) Cooking reactions **double** for every **~10 ºC** (beyond 100 ºC)!

Phase diagram of water. If we take a block of ice at atmospheric pressure and slowly raise its temperature, it melts completely at 273 K (0 ºC) and remains liquid until 373 K (100 ºC), whereupon it completely vaporizes.



"O" is triple point water - solid, liquid and gas /vapor co-exist.
Temp = 0.01 ºC.

"C" is a critical point – above this gas does **not liquefy** or **solidify** – it only gets **denser** as pressure increases. Example: Jupiter's atmosphere (H, He).

Heat Applications (Chapter 10/11)

Heat Flow (three basic means):

- Conduction **- Convection** **- Radiation**

Very important for understanding heat loss (gain) e.g. a house.

Conduction:

- Heat flows through material objects that are in **contact-** from **higher** to **lower temperature**.
- Flow rate depends on **temperature difference**, and **"thermal conductivity"** of materials.

➢ Metals are **good conductors** of heat (& electricity)

➢ Plastics, wood are **poor conductors** of heat (& electricity).

Metal and wood at room temperature: **Metal feels colder** as it has a **higher thermal conductivity** and can **remove heat** from hand more **rapidly.**

TABLE 13.7

APPROXIMATE VALUES* OF THERMAL CONDUCTIVITIES

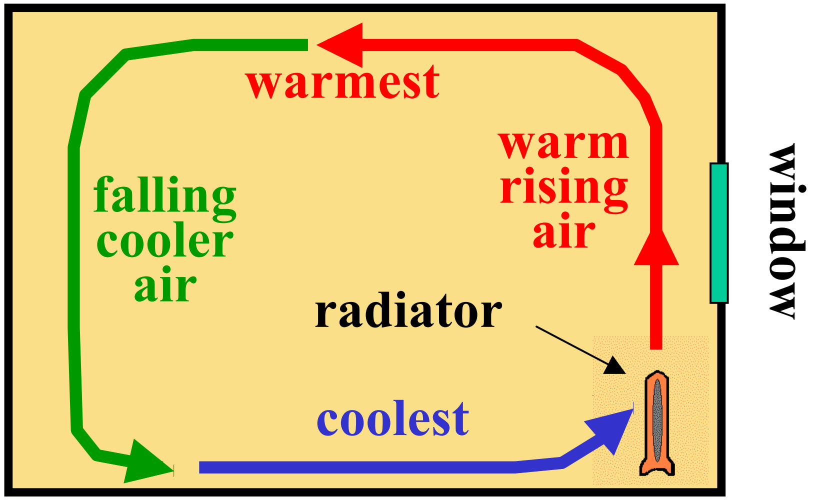
	Material	Thermal conductivity, k_T (W/m·K)	Material	Thermal conductivity, k_T (W/m·K)	
	Metals		Linen	0.088	
	Aluminum	210	Paper	0.13	
	Brass (yellow)	85	Paraffin	0.25	
LARGE	Copper	386	Plaster of Paris	0.29	
	Gold	293	Polyamides (e.g., Nylon)	0.22–0.24	
	Iron	73	Polyethylenes	0.3	
	Lead	35	Polytetrafluroethylene		
	Platinum	70	(e.g., Teflon)	0.25	
LARGE	Silver	406	Porcelain	1.1	
	Steel	≈46	Rubber, soft	0.14	
	Other solids		Sand, dry	0.39	
	Asbestos	0.16	Silk	0.04	
	Brick, common red	0.63	Snow, compact	0.21	
	Cardboard	0.21	Soil, dry	0.14	
	Cement	0.30	Wood, fir, parallel to grain	0.13	
	Chalk	0.84	***Liquids***		
	Concrete and cement mortar	1.8	Acetone	0.20	
	cinder block	0.7	Benzene	0.16	
	Down	0.02	Alcohol, ethyl	0.17	
	Earth's crust	1.7	Mercury	8.7	
	Felt	0.036	Oil engine	0.15	
	Flannel	0.096	Vaseline	0.18	
	Glass	0.7–0.97	Water	0.58	
	fiberglass	0.04	***Gases***		
	Granite	2.1	Air	0.026	VERY LOW
	Human tissue (no blood)	0.21	Carbon dioxide	0.017	
	fat	0.17	Nitrogen	0.026	
	Ice	2.2	Oxygen	0.027	
	Leather	0.18			

*Near room temperature.

- **Heat flow** is transfer of **kinetic energy** and "**free electrons**" in metals are **key to conduction** (heat and electricity).
- **Insulators:** Still air – porous materials with trapped pockets of air (wood, fiberglass, foam, peanuts…).

Convection:

- Transfer of heat by **motion of a fluid** containing thermal energy.
- **Main way** to heat a house (large volume).
- Warm air is **less dense** and **rises** (like a hot air balloon).
- Sets up an **air current** within a room.



- **Blankets** trap your heat and **reduce convection**.

Question: Why put radiators under a window?

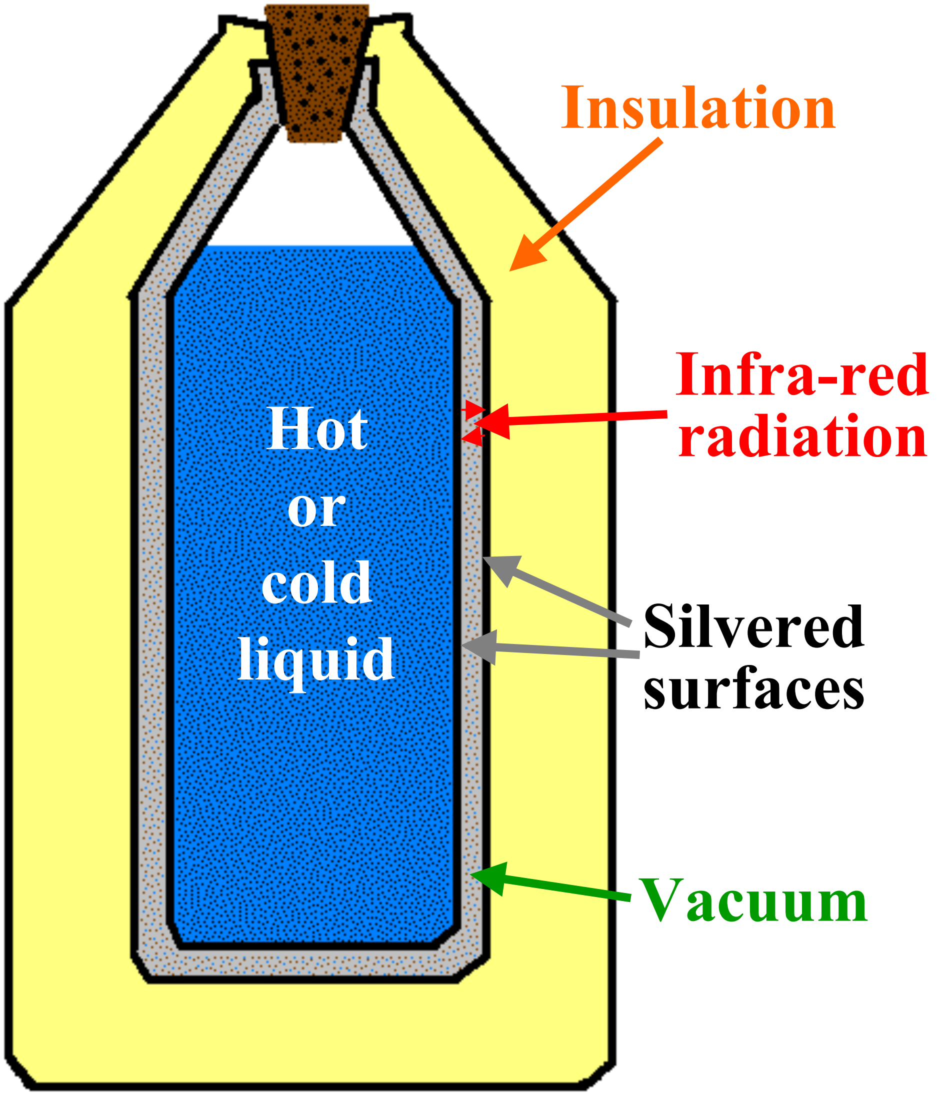
Answer: **Enhances convection** as cool air **more dense** and it helps mix the air to remove cold pool of air next to window.

Radiation:

- Involves the flow of **electromagnetic waves** (i.e. heat in the form of infra red radiation).
- Unlike conduction and convection, **radiation** does **not** require a **medium to propagate** through.
- **Radiation** can therefore **propagate** through a **vacuum**! (e.g. solar radiation). If not then no life on Earth!
- Radiation transmission is reduced to **minimum by silvering** surfaces which then **reflect the energy back** into building.
- If not "silvered" then radiation will be **absorbed** by a vessel or wall and it will heat up. Resultant heat will then be **lost** by **conduction** and **convection**.
- **Foil backed insulation** is used in housing to limit heat loss by **conduction and radiation.**

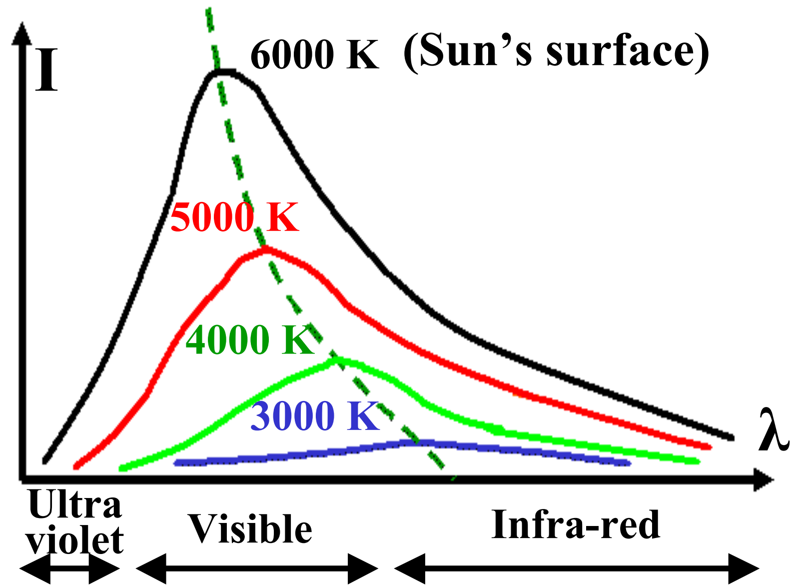
Thermos Flask

- Designed to **isolate** the liquid from the outside.
- Stops **heat conducting** or **radiating out**, keeping hot liquid inside.
- Stops heat **entering** flask, keeping cold liquid inside.
- **No convection**, except (possibly in trapped liquid) with no loss of heat.



Solar Radiation and Energy Flow

- Plot of **radiation** from a body as function of its **temperature**:
- Higher the temperature, the more energy (I) and the shorter the wavelength (λ) of emission.



- At temperatures below 1000 K the radiation is all infrared… (long wavelength).
- The amount of thermal radiation **emitted** by a body depends on its **surface condition** (color, texture, area) and its **temperature**.
- Amount of **energy absorbed** also depends on **surface condition** and on properties of **incident radiation**.

General rule: A good emitter is a good absorber.

- Rough, black surfaces radiate (and absorb) effusively.
- Polished silver and copper 20-30 times less radiation.
- White surfaces are in-between…

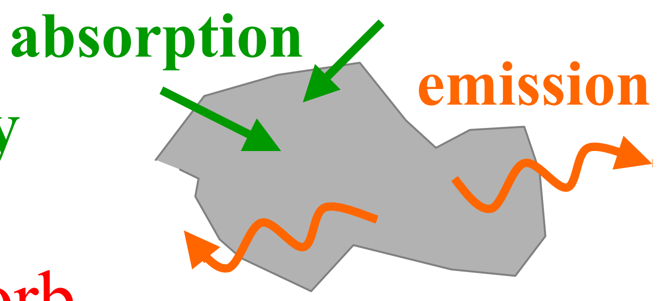
Thermal Equilibrium

- An object bathed in radiant energy from a higher temperature source will absorb energy and increase its temperature.
- As its temperature rises it will **emit** more and an equilibrium is reached where emission **equals** absorption.

E.g. Parking car in sunshine – black heats up more quickly and to a higher equilibrium temperature than white!

- The larger the area exposed the more energy absorbed and more rapidly temperature will rise
- In deep space a hot body will radiate until it cools to ambient temperature of 3 K (due to radiation from distant sources).

Summary:



- **All bodies radiate and absorb energy continuously.**
- Hot bodies radiate more than they absorb and thus cool to surrounding temperature (and vice versa).

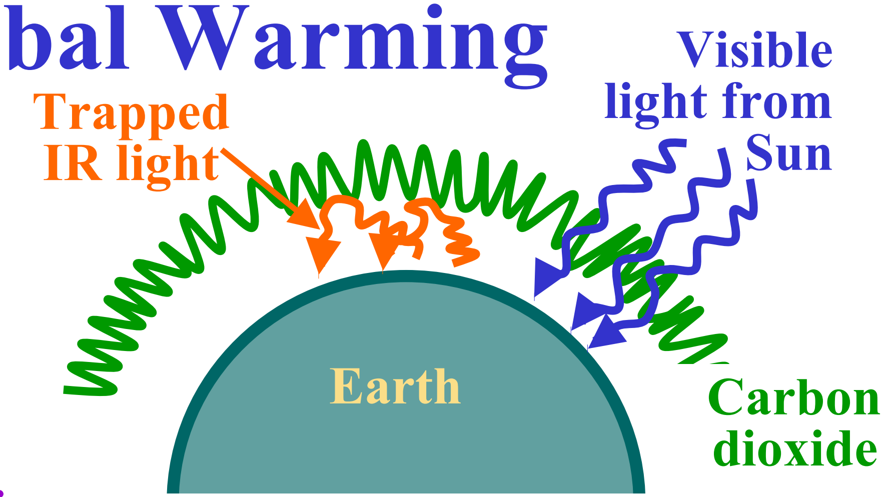
Greenhouse Effect

- Relies on fact that glass (or plastic) is **transparent** to visible radiation but **opaque** to infra-red (IR) radiation.
- E.g. Car window closed – visible radiation only transmitted. Car window open – you absorb visible, IR and ultra-violet radiation – get sun burnt!

Greenhouse: Traps air (reducing convection). The air is then **heated up** by solar radiation. **Steps:**

1. Visible light **passes through glass** into greenhouse and is **absorbed** by soil, plants etc. (IR is reflected).
2. Soil heats up and **emits IR** radiation.
3. IR radiation is **reflected back** into greenhouse by **glass walls** and **roof** (its trapped!).
4. More radiation is **absorbed** by soil etc. and **greenhouse heats up** (until balanced by conduction losses at wall etc.).
5. Can get very high temperatures inside (on a sunny day) even if cold outside. Open windows to let heat escape (car too!).

Atmosphere: Global Warming



Main "greenhouse" gases

- The CO_2 and H_2O gases in atmosphere are **opaque** to IR radiation and hence trap heat in lower atmosphere.
- Carbon dioxide (CO_2) and water vapor (H_2O) are in large quantities in the atmosphere.
- CO_2 produced by volcanoes, burning fossil fuels etc. is moderated by plant absorption (and by oceans).
- Rise in CO_2 acts to **trap heat** which in turn will create more **H_2O vapor** and problem **worsens!**
- Produces overall **increase in global temperature** and much more varied and potentially violent weather.
- Result: **Melting polar** caps and consequent **sea level rise**. Also change in **salinity** can cause deep **ocean currents** (e.g. Gulf stream) to **stop.** Possibly triggering next **Ice Age.**

Thermal Expansion

- An ancient knowledge – we all know that substances (solids, liquids, gases) expand when heated (and vice versa).

Linear expansion: (rod, bar etc)

- The change in length of a solid bar (ΔL) depends on:
  - change in temperature ΔT
  - original length L_0
  - Coefficient of linear expansion, α

$\mathbf{\Delta L = \alpha . L_0 . \Delta T}$ (where: ΔT in K or ºC)

- Expansion occurs at the atomic level. As heat bar atoms vibrate with larger amplitude and their mean separations increase … This causes an expansion of the whole rod.
- The more heat added (i.e. larger ΔT), the larger the expansion (until it melts).
- ΔL expansion is a percentage variation and so depends on original length L_0…
- E.g. 5% of 1m = 0.05 m, but 5% of 10 m = 0.5 m

- Expansion is usually quite small – typical metals expand about 7% when temperature rises from near 0 K to its melting point.
- Most materials have a positive coefficient of linear expansion (except rubber under tension shrinks!)
- Coefficient α depends on atomic structure. E.g. lead is a soft metal that is easily melted and its atoms are less tightly bound. It therefore has a high coefficient of expansion (29×10^{-6} K^{-1}).
- In comparison, Pyrex glass has very low value of α (3×10^{-6} K^{-1}) and quartz even lower (about 50 x less than lead).

Result: Buckled railroad track if rails too long.

- Now we use very low expansion steel alloy to stop buckling of continuous track.

Volumetric expansion (Solids and liquids):

- Analogous to linear expansion, volumetric expansion:

$$\Delta V = \beta . V_0 . \Delta T \quad \text{(Note: } \beta \approx 3 \text{ times } \alpha \text{ for solids).}$$

- Liquids are not bound like solids and their volume coefficient of expansion is much larger (around 50 times) that of a solid volume.
- (Note: Both α and β are dependent on temperature as well.)

Results:

- Bimetal strip bends when heated – used for thermal sensor switches, car indicators…
- Bridges expand in summer (and vice versa) – need expansion joints. E.g. Bay bridge in San Francisco contracted 1.3 m in 1937!
- Dental fillings have same coefficient of expansion as teeth to stop them cracking!
- Loosening metal lids on glass jars – metal expands more than glass when warmed.

Approximate Values* of Coefficients of Linear Expansion

Material	Coefficient (α) (K^{-1})
Aluminum	25×10^{-6}
Brass (yellow)	18.9×10^{-6}
Brick	10×10^{-6}
Diamond	1×10^{-6}
Cement and concrete	$10-14 \times 10^{-6}$
Copper	16.6×10^{-6}
Glass (ordinary)	$9-12 \times 10^{-6}$
Glass (Pyrex)	3×10^{-6}
Glass (Vycor)	0.08×10^{-6}
Gold	13×10^{-6}
Granite	8×10^{-6}
Hard rubber	80×10^{-6}
Invar (64% Fe, 36% Ni)	1.54×10^{-6}
Iron (soft)	$9-12 \times 10^{-6}$
Lead	29×10^{-6}
Nylon (molded)	81×10^{-6}
Paraffin	130×10^{-6}
Platinum	8.9×10^{-6}
Porcelain	4×10^{-6}
Quartz (fused)	0.55×10^{-6}
Steel (structural)	12×10^{-6}
Steel (stainless)	17.3×10^{-6}

*At temperatures around 20°C.

Approximate Values* of Coefficients of Volumetric Expansion

Material	Coefficient (β) (K^{-1})
Solids	
Aluminum	72×10^{-6}
Asphalt	$\approx 600 \times 10^{-6}$
Brass (yellow)	56×10^{-6}
Cement and concrete	$\approx 36 \times 10^{-6}$
Glass (ordinary)	$\approx 26 \times 10^{-6}$
Glass (Pyrex)	9×10^{-6}
Invar	2.7×10^{-6}
Iron	36×10^{-6}
Lead	87×10^{-6}
Paraffin	590×10^{-6}
Porcelain	11×10^{-6}
Quartz (fused)	1.2×10^{-6}
Steel (structural)	36×10^{-6}
Liquids	
Acetone	1487×10^{-6}
Ethyl alcohol	1120×10^{-6}
Gasoline	950×10^{-6}
Glycerin	505×10^{-6}
Mercury	182×10^{-6}
Turpentine	973×10^{-6}
Water	207×10^{-6}

*At temperatures around 20°C.