AML 883 Properties and selection of engineering materials

LECTURE 14. DBTT, manipulating toughness and fatigue resistance, and thermal properties of materials

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DBTT: Ductile-to-brittle transition

- Cleavage fracture: dangerous (no warning)
- Low temperatures (as compared to Tg): polymers become brittle
- Metals too undergo a ductile-to-brittle transition
- Only metals and alloys with fcc structure remain ductile to the lowest temperatures
- Yield strengths increase as temperature falls
- Plastic zone at the crack tip shrinks
- Fracture mode switches

DBTT

- Suppose the transition temperature is 0 degree C
- In winter, in colder climates, material will fail
- Ships, bridges, oil rigs – fail and lead to catastrophes
- Similarly, polymers to be used in freezers and fridges – carefully needs to be selected

Embrittlement

- Chemical segregation can introduce embrittlement
- Liquid metals (like mercury) can cause embrittlement
- Hydrogen can induce embrittlement

Manipulating toughness

Metals and alloys

- Strong and tough: not an easy combination to achieve
- Why?

Plastic zone

- Energy absorption ahead of the crack: require the material to have lower yield strengths and larger plastic zones
- Strength: we want higher yield strength
- Conflict!

Avoid inclusions

- Void nucleation – typicallly at inclusions
- Removal of inclusions by filtering the molten metal before casting -- “clean” steels, superalloys, and aluminium alloys – increase toughness without loss of strength

Polymers and composites

- Cross-linking, molecular weight (extent of polymerisation) and degree of crystallanity – manipulate to get desired properties
- Blending
- Adding fillers
- Here again – what improves strength decreases fracture toughness and vice versa
- Reinforcement – an exception!

Reinforcement

- Can increase both strength and fracture toughness
- How?
- Fine fibres – contain small flaws – consequently, higher strengths
- Bridges cracks
- Overall energy dissipation is high!
- Debonding and pull out – also cost energy

Manipulating fatigue

Enhancing fatigue life

- Choose strong materials
- Make sure that the defects are as few (and small) as possible
- Give a surface layer that is compressive

Endurance limit and strength

- Increasing yield strength leads to decreasing endurance limit
- Non-destructive testing (X-ray imaging and ultrasonic testing) – to detect flaws and reject those which are defective
- HIP – Hot isostatic pressing – to seal cracks and collapse porosity

Compressive surface stress

- Shot peening, sand blasting, burnishing, diffusing atoms into surface, ...: plastically compress the surface

Summary

Summary

- Structural materials: stiffness, strength, and toughness
- Materials properties of interest: density, modulus, yield strength, ductility, fracture toughness, strain energy release rate (toughness), damping coefficient, endurance limit, ...
- Mechanisms, measurement and manipulation

Before we proceed to functional materials

Effect of heat in mechanical and physical properties

Thermal properties

- Response of materials to heat
- What is heat?

Heat

- Atoms and molecules in motion
- Gas – flying molecules with occasional collisions
- Solid – vibration about mean positions – with ever increasing amplitudes with increasing temperatures

Thermal design

- Design of materials for coping properly with the effects of heat, or, where possible, exploit them
- Example: heat exchanger – a device for efficient transfer of heat between two media

Heat exchangers

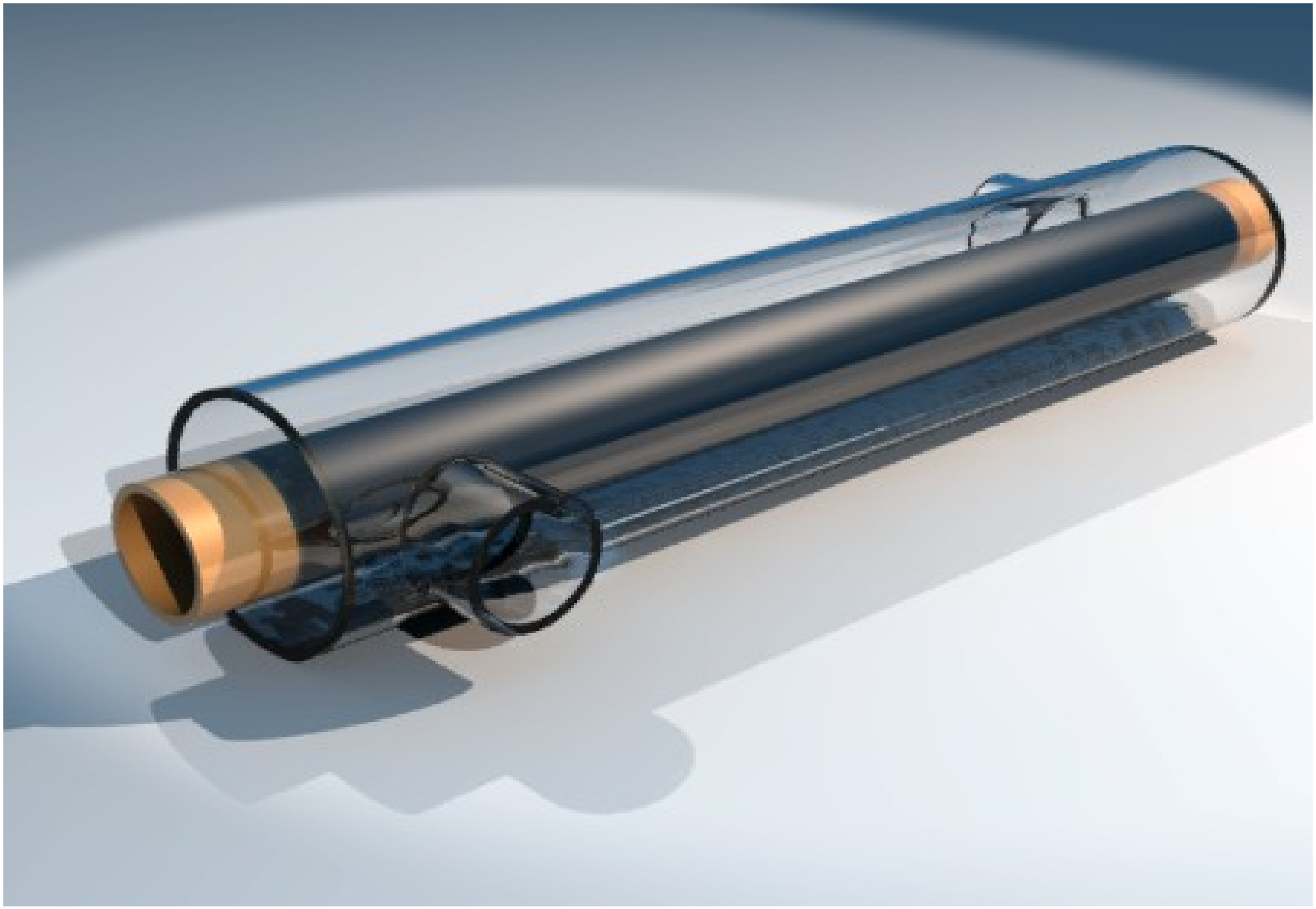


Image courtesy: wiki

Fundamental points of reference

- Melting temperature
- Glass transition temperature
- Relate directly to the strength of the bonds in the solid
- Crystals – sharp melting point; non-crystalline – no sharp melting point
- Glass transition – true solid to very viscous liquid transition

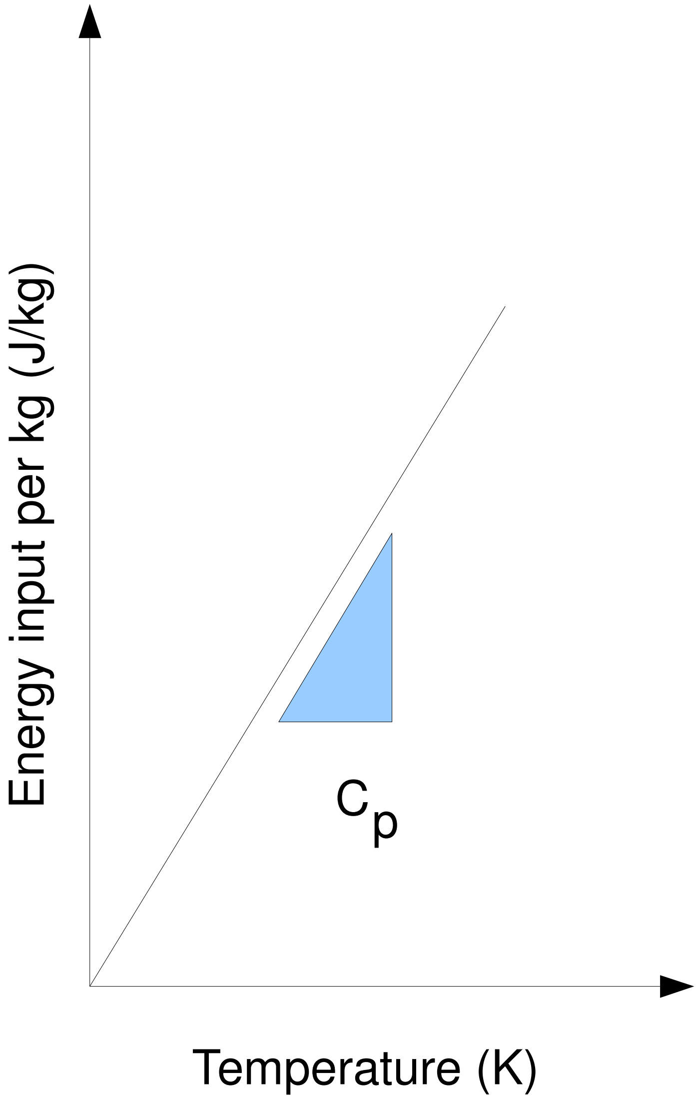
Service temperatures

- Maximum service temperature: maximum temperature at which material can be used continuously without oxidation, chemical change or excessive distortion
- Minimum service temperature: minimum temperature below which the material becomes brittle or unsafe to use

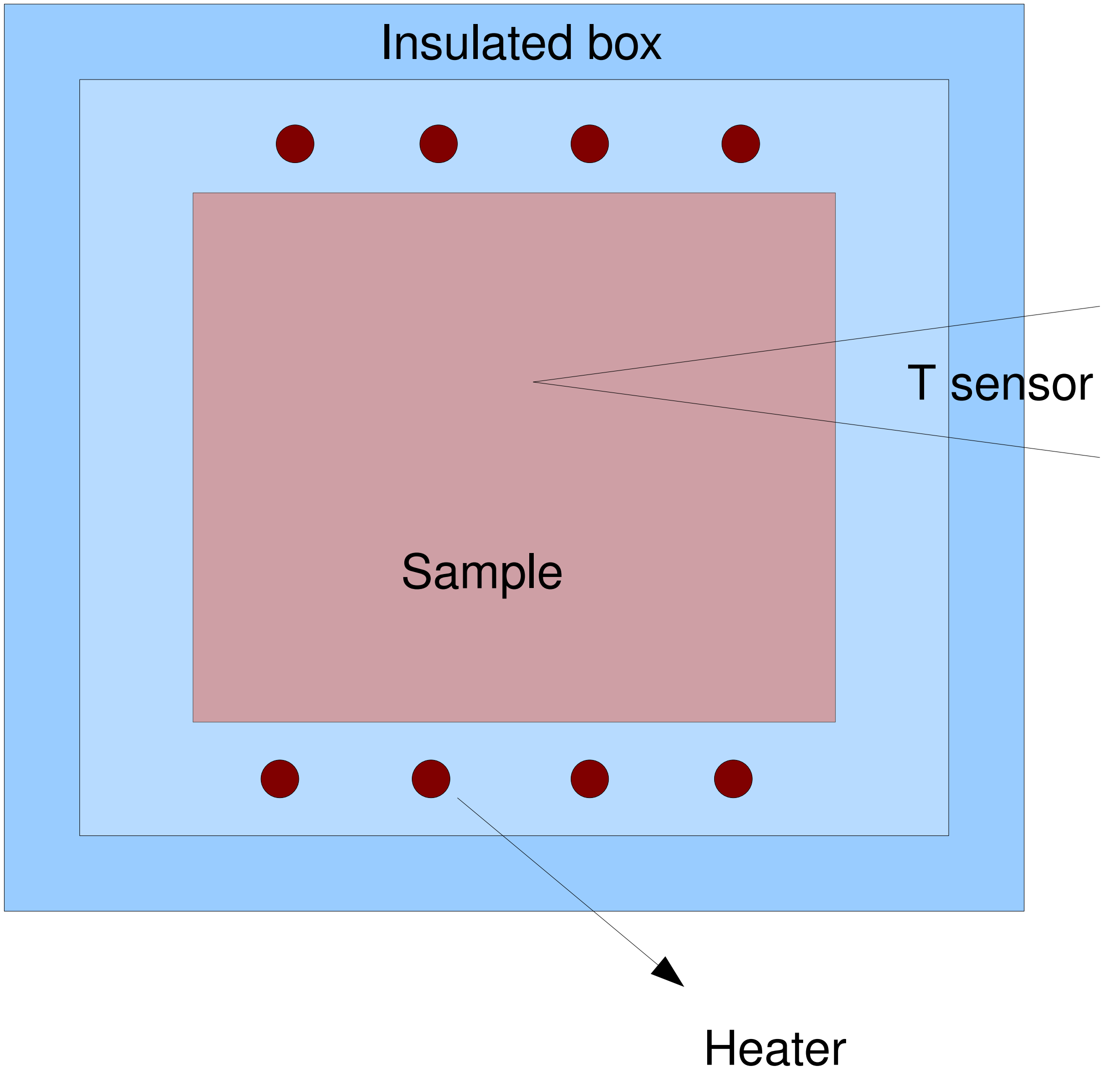
Heating materials up!

- Costs energy to heat materials up
- Heat capacity or specific heat – energy to heat 1kg of material by 1K
- Constant pressure and constant volume heat capacities -- different
- Solids – difference between the two heat capacities is negligible; neglected here!
- Units: Joules/ kg K

Measuring heat capacity



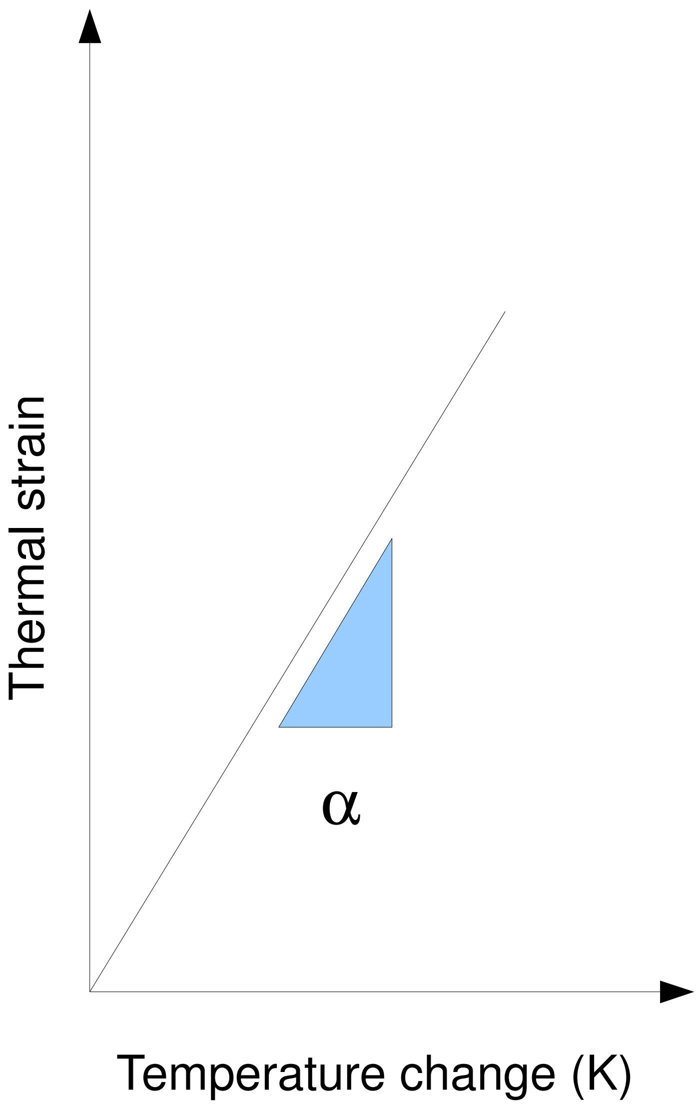
Calorimetry: pump a mesured quantity of heat into the material of known mass and measure the raise in T

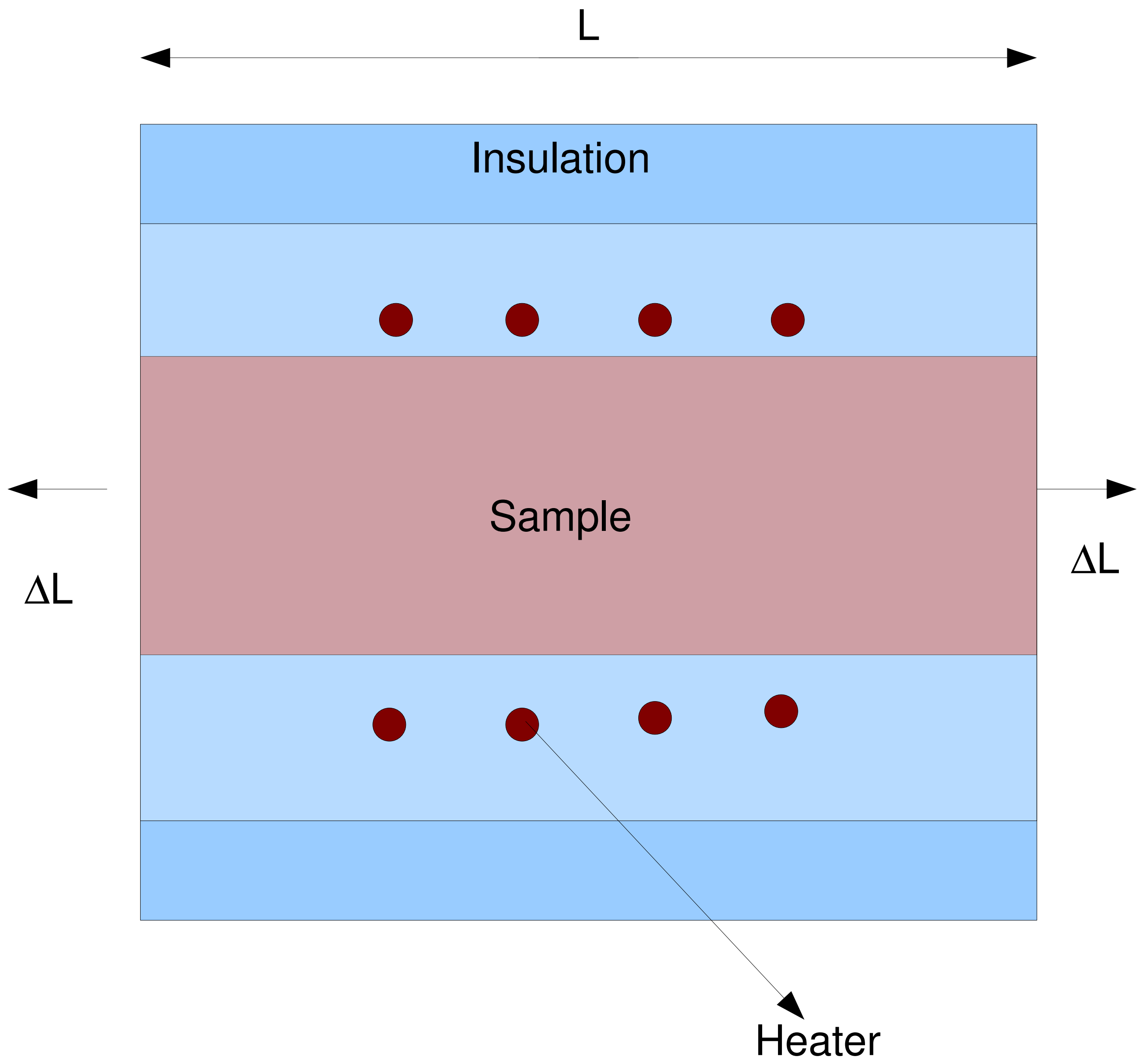


α

- Linear thermal expansion coefficient
- Thermal strain per degree of temperature change
- Isotropic bodies: $\alpha = (1/L)(dL/dT)$
- Anisotropic bodies: two or more coefficients are needed
- Units: Kelvin inverse

Measuring α

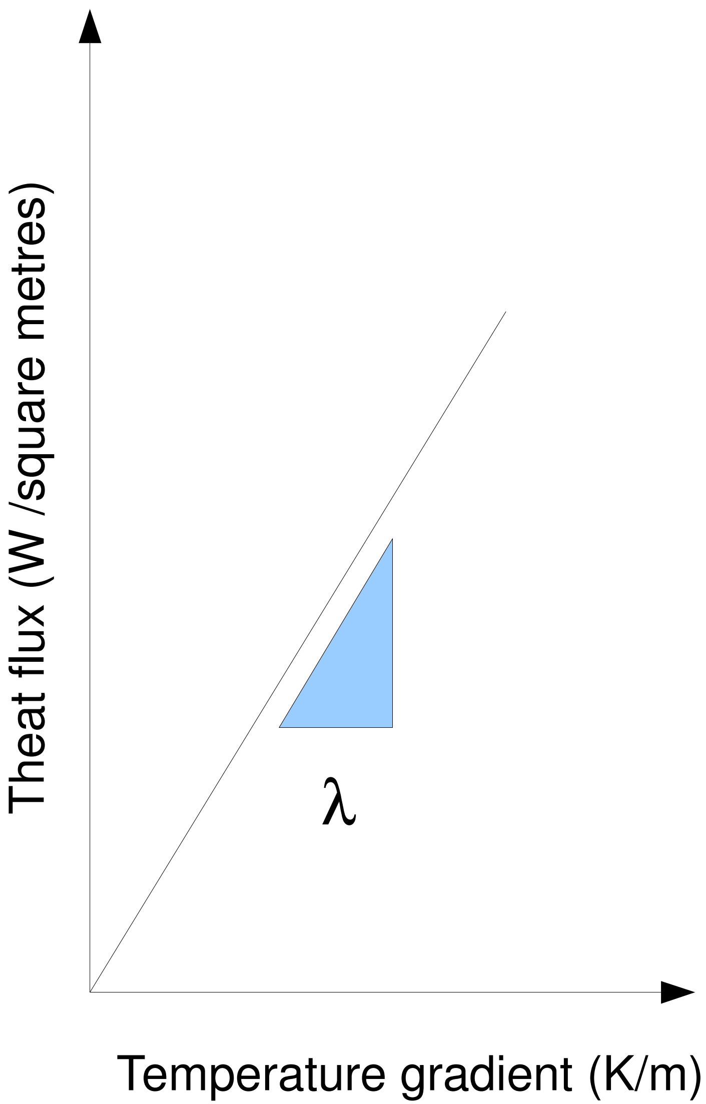


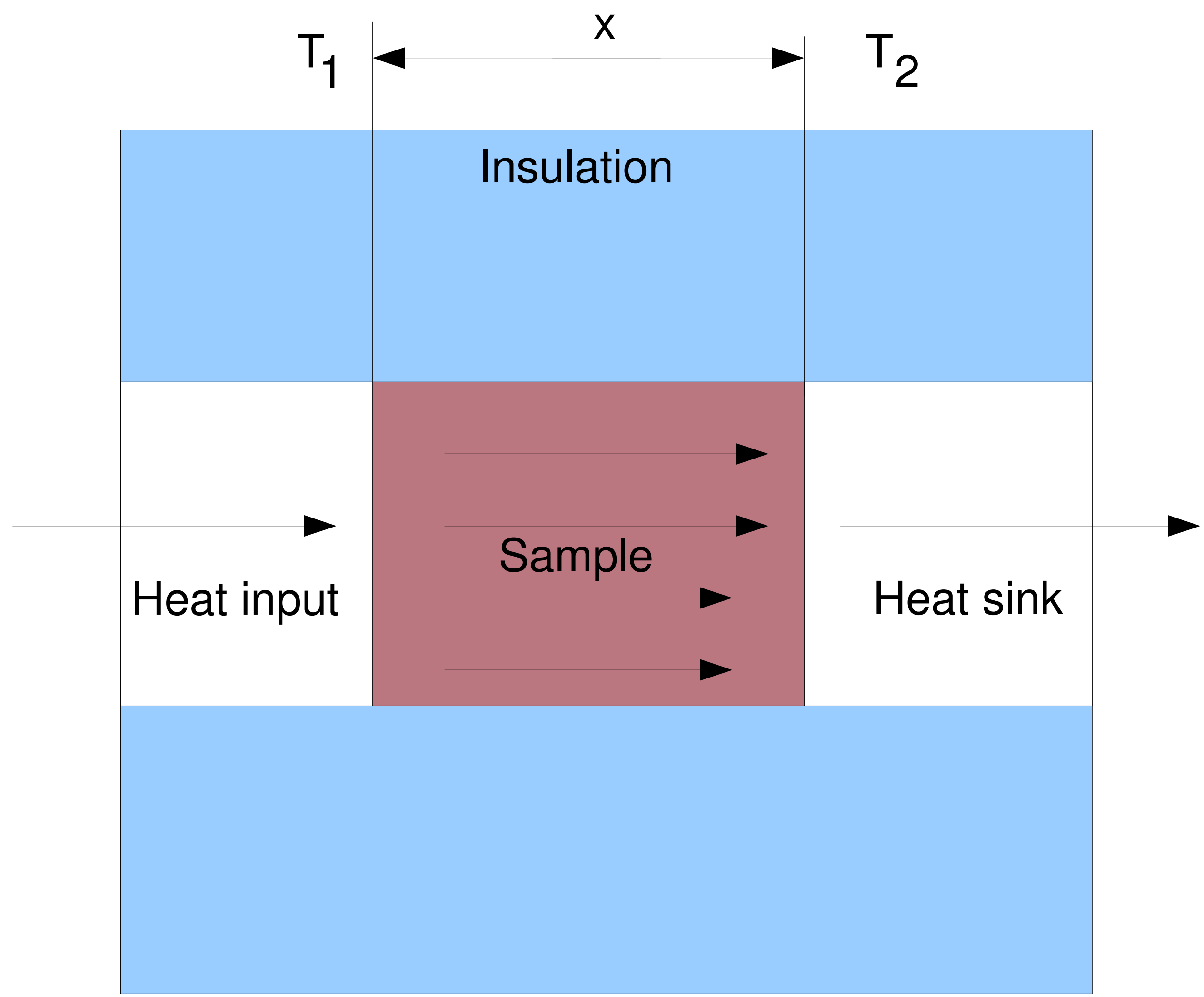


Thermal conductivity

- Rate at which heat is conducted through a solid at steady state (temperature profile does not change): thermal conductivity
- Units: Watts / m K
- Watt – Joule / second

Measuring λ





Use Fourier's law to measure conductivity

Thermal diffusivity

- Conductivity: flow of heat at steady-state in a material
- Diffusivity, 'a': transient heat flow (flow of heat when temperature varies)
- Units: square metres / second
- $a = \lambda / (\rho C_p)$
- ρ -- Density

Whither?

- Applications where these properties become important
- Design and materials property charts
- Origins of thermal properties
- Manipulating thermal properties