23rd IYPT Problem : Ice

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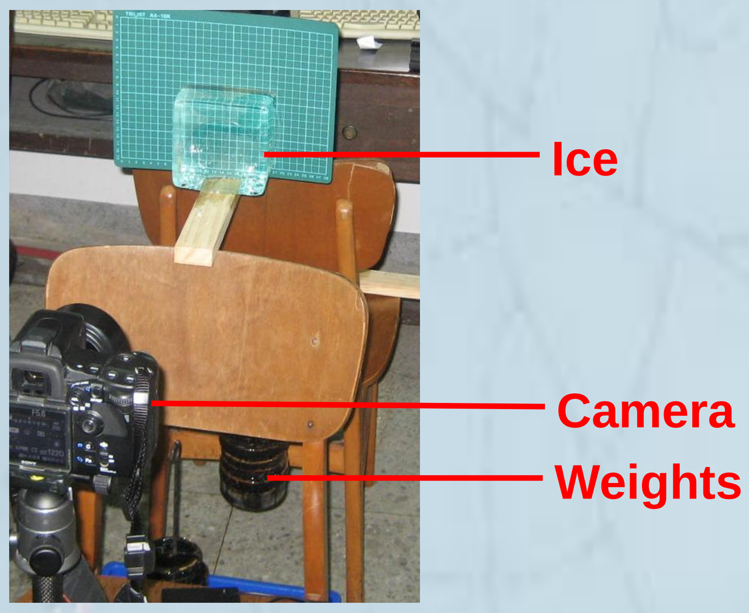
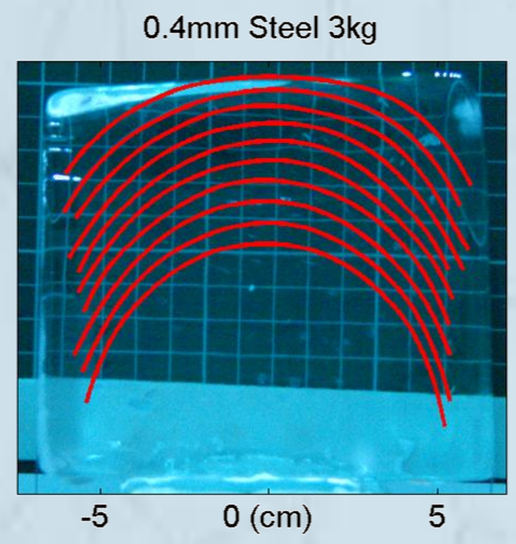
Abstract

A wire with weights attached to each end is placed across a block of ice. The wire may pass through the ice without cutting it. Investigate the phenomenon.

The phenomenon is known as the regelation of ice. According to the phase diagram of water, we suggest that ice tends to meld when pressure is added; the melted ice solidify after pressure releases. Experiments concerning pressure, wire thermal conductivity, and wire curvature support our theory. The results indicate the "pressure effect" dominates the cutting. For more accurate theoretical model, external heat input and water flow should also be considered.

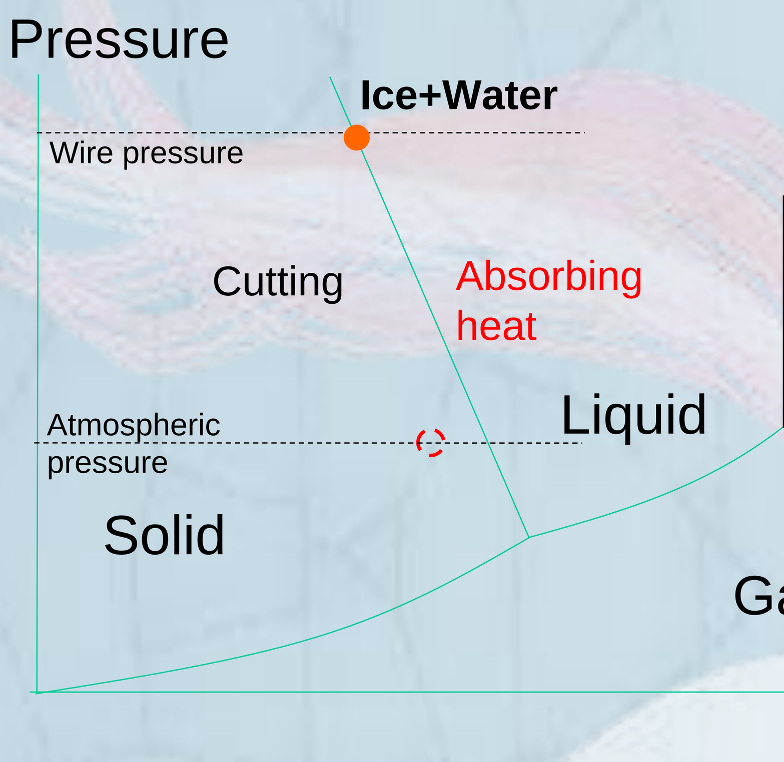
Experimental Setup and Typical Result

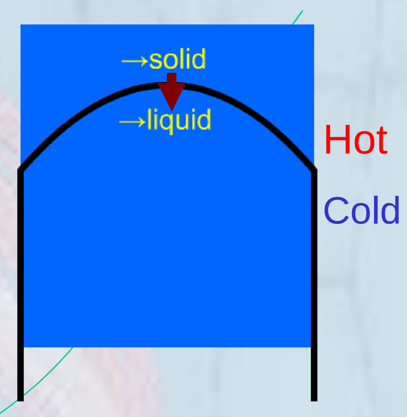


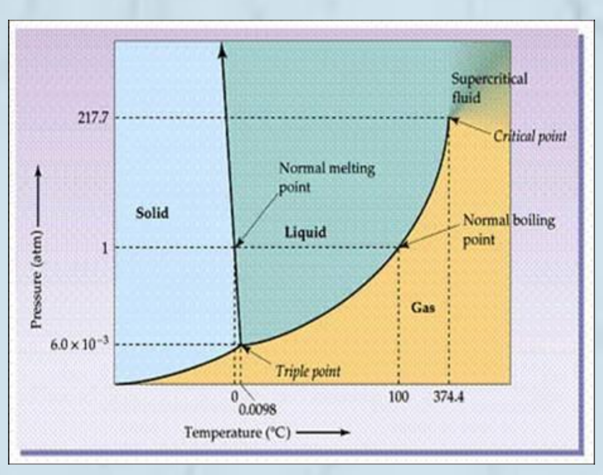


Duration: 1 hr

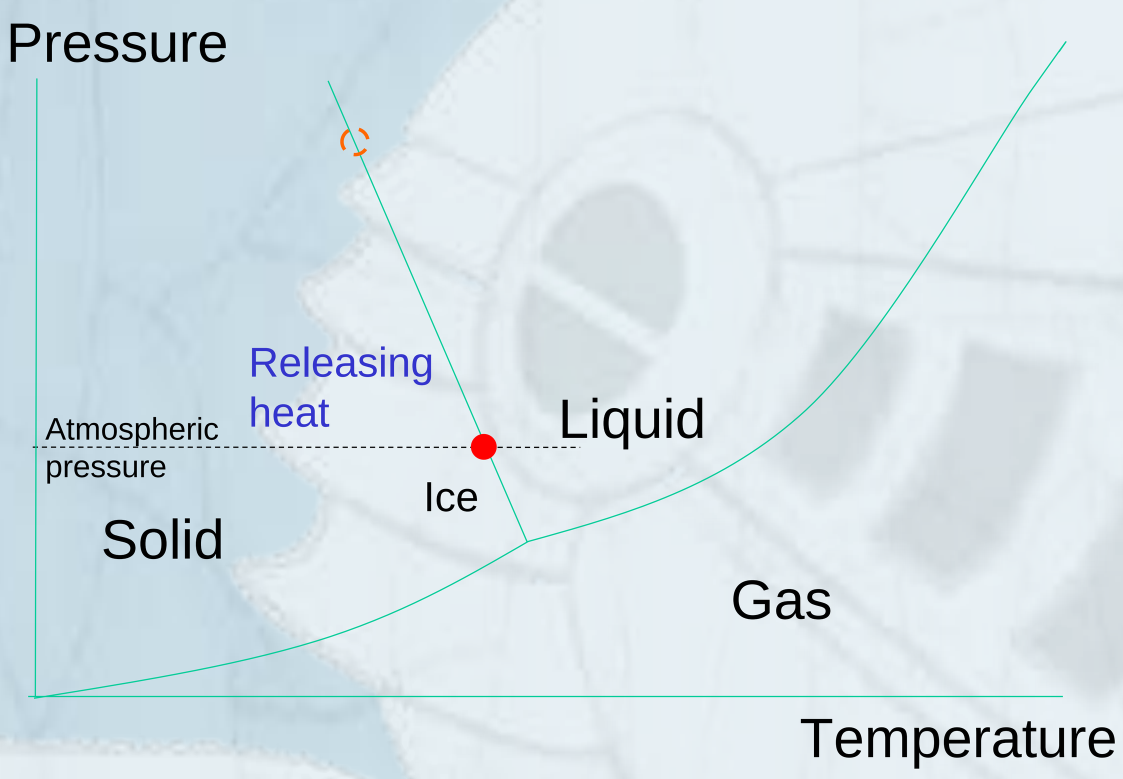
Pressure Effect





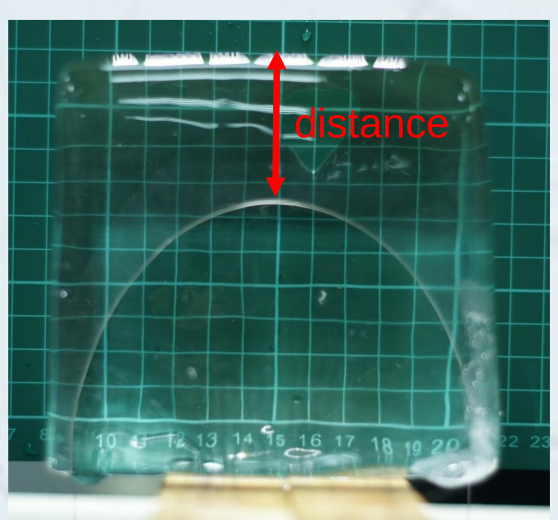


Source: www.asa3.org/



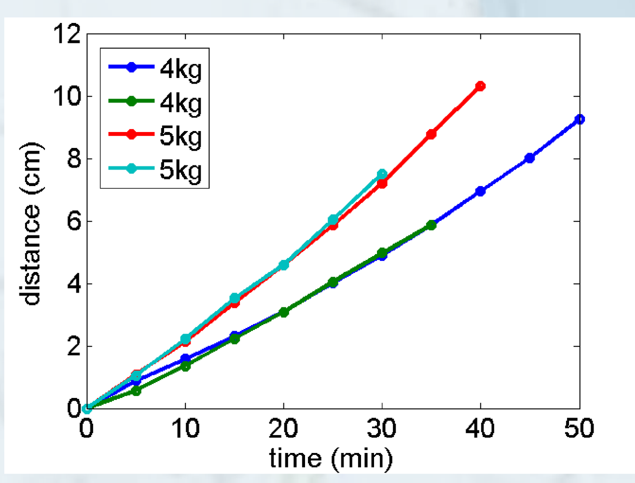
- Ice under the wire tends to melt.
- According to the phase diagram, melted ice is colder. The temperature difference results in heat conduction.
- After cutting, the water regelates and returns to original state.

Experimental Results



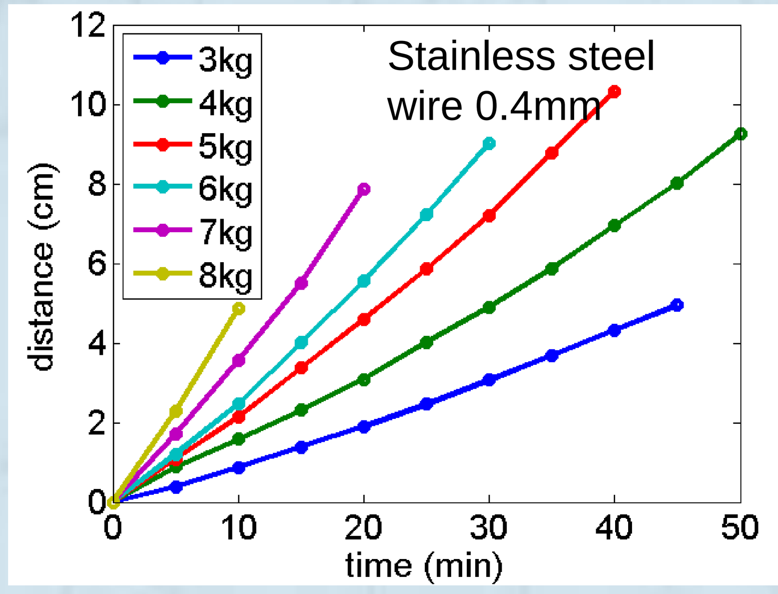
- The cutting is described by the speed of wire center after it sinks into the ice.

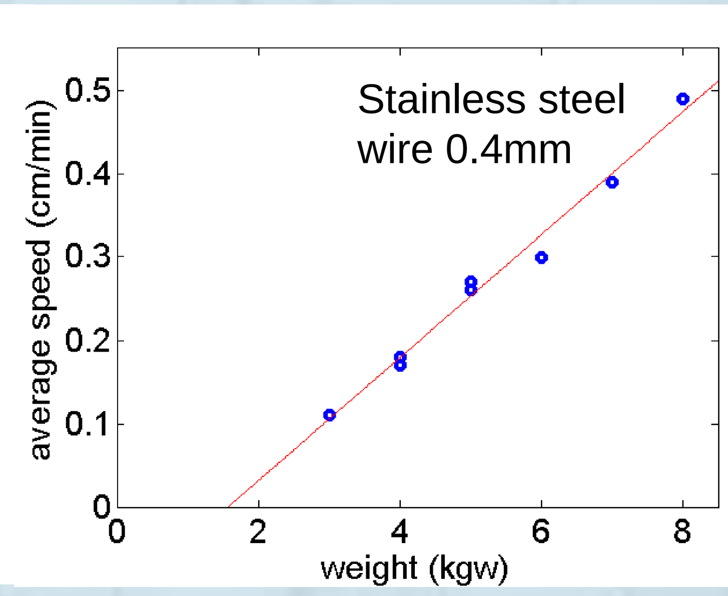
Ambient Temperature



- Experiments with the same conditions except ambient temperature are repeated twice.
- The "speed at center" is almost constant.
- Repeatable in different temperature (23°C~28°C).
- Ambient heat fluctuation can be neglected.

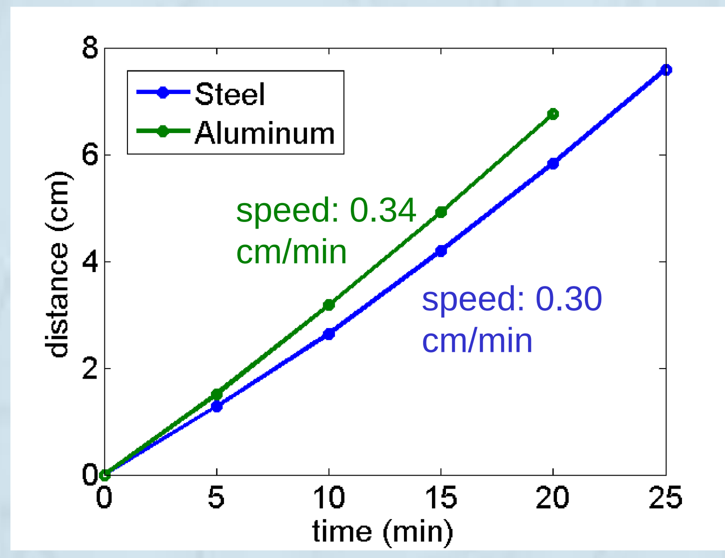
Weight





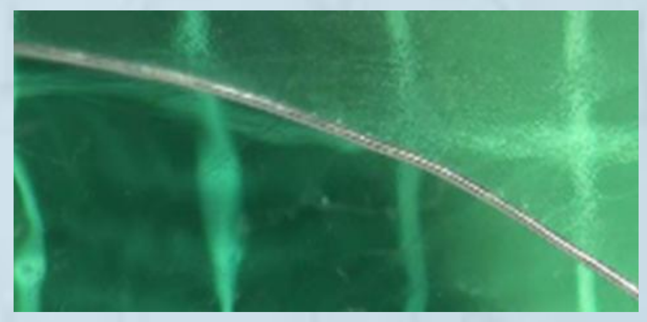
- The wire cuts faster when pressure is higher.
- There is a minimum pressure required to melt the ice.

Thermal Conductivity



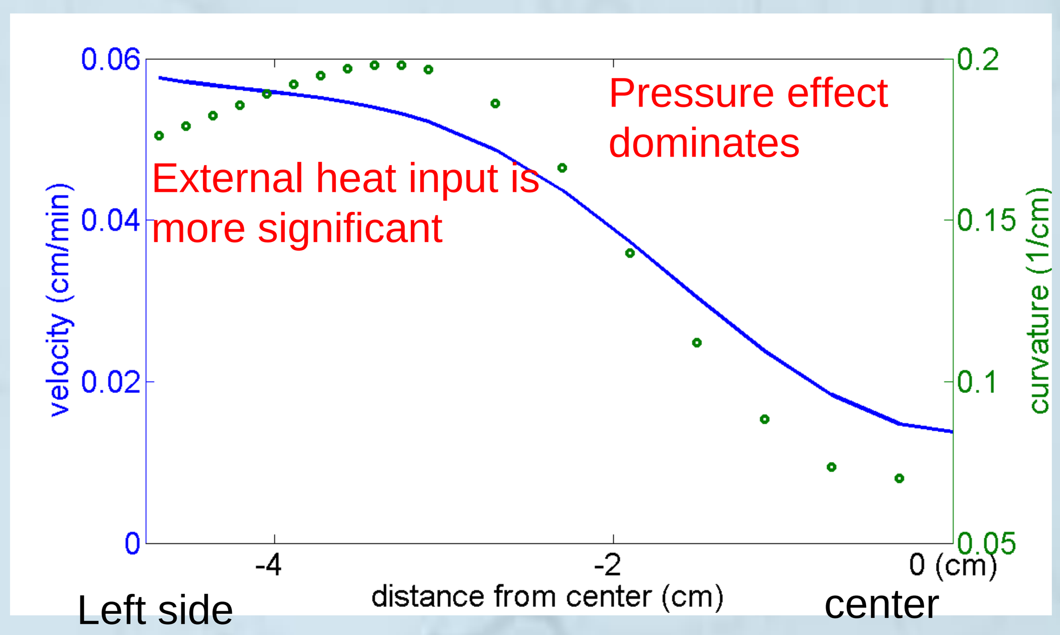
Thermal Conductivity (W/m-K)

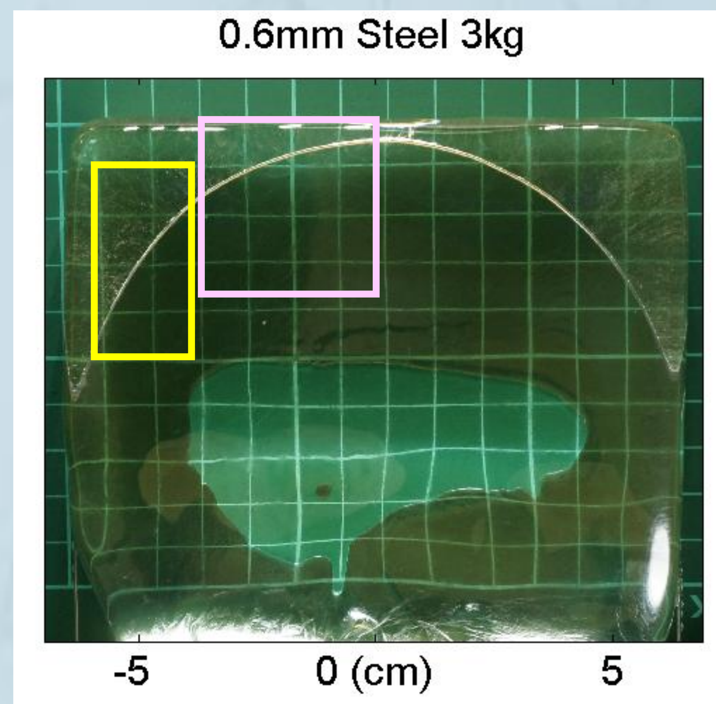
- Aluminum : 235
- Steel : 16.3
- Good thermal conductor cuts faster.



- Water flow observed in the cutting process may also contribute to the thermal conduction.

Curvature

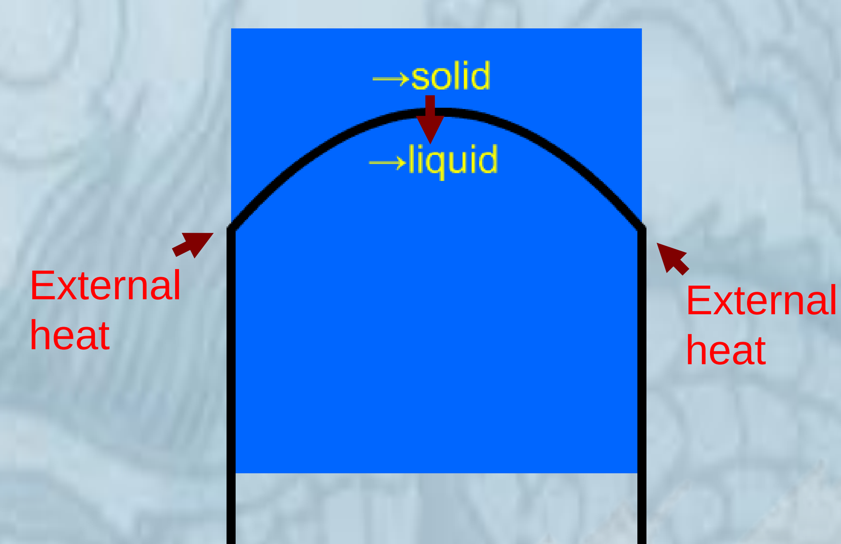




- At the center of ice, cutting speed is positively related to the curvature.
- At the sides of ice, external heat input is more significant and results in faster cutting speed.

External Heat Effect

- Water melts due to external heat input
- It can solidify again because the temperature inside the ice is below 0°C (-15°C~ -0.3°C).



Mathematical Estimation

- Heat conduction rate:

$$\frac{dQ}{dt} = k\frac{A}{d}\Delta T = L\frac{dm}{dt} = L(\rho A v)$$

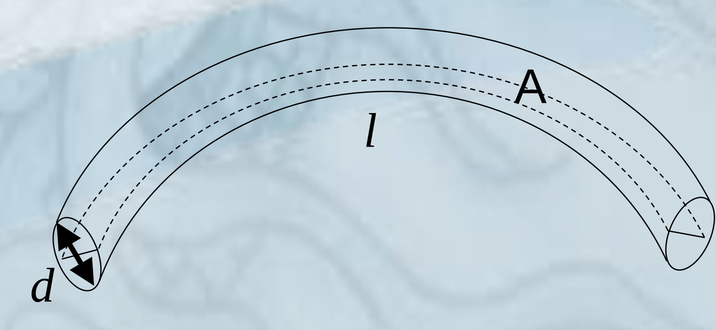
- From Clausius-Clapeyron equation,

$$\frac{\Delta P}{\Delta T} = \frac{\rho L}{T_0}$$

- Center speed upper limit

$$v \approx 10^{-1} cm/\min$$

- Pressure effect plays an important role.



Summary

- The wire passes through the ice
  - Pressure effect
  - External heat effect
- The ice regelates (without being cut)
  - Pressure releases
  - Temperature inside the ice is below 0°C