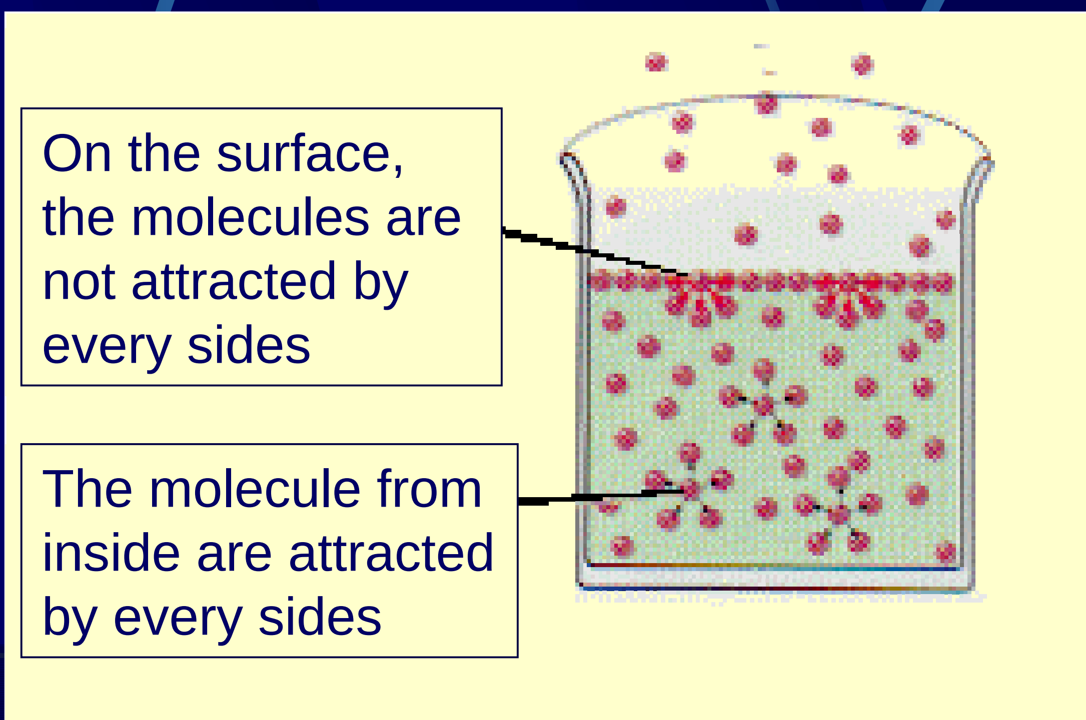
2. Stubborn Ice

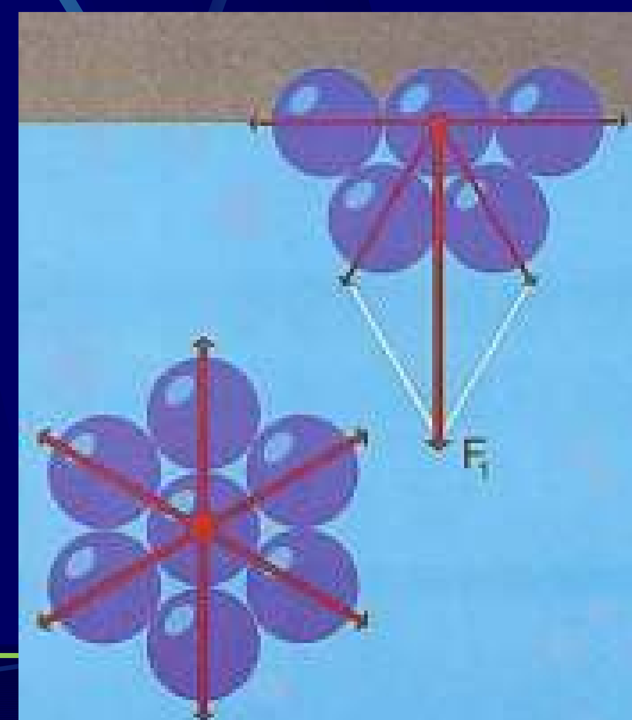
"Put a piece of ice (e.g. an ice cube) into a container filled with vegetable oil. Observe its motion and make a quantitative description of its dynamics."

2.1. Theory

2.1.1. Surface tension

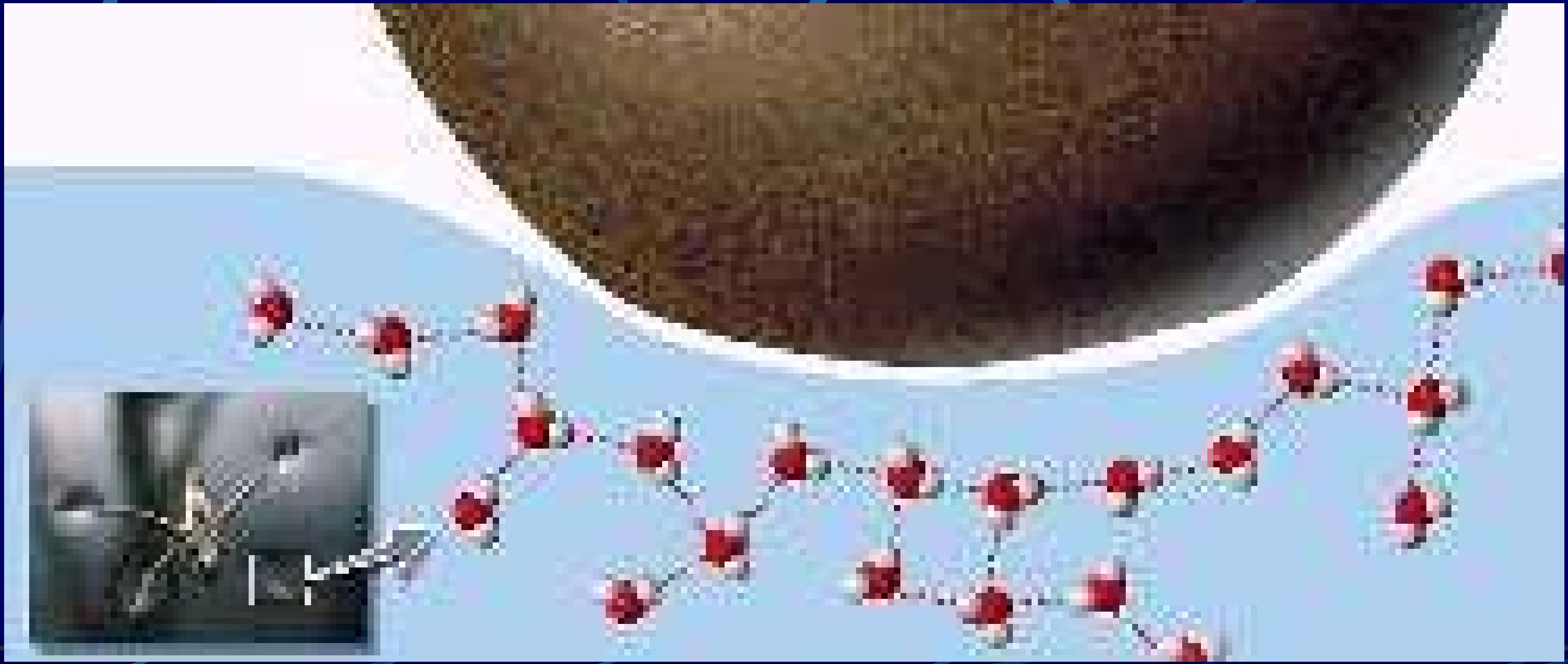
Makes the surface looks like a tensioned rubber sheet





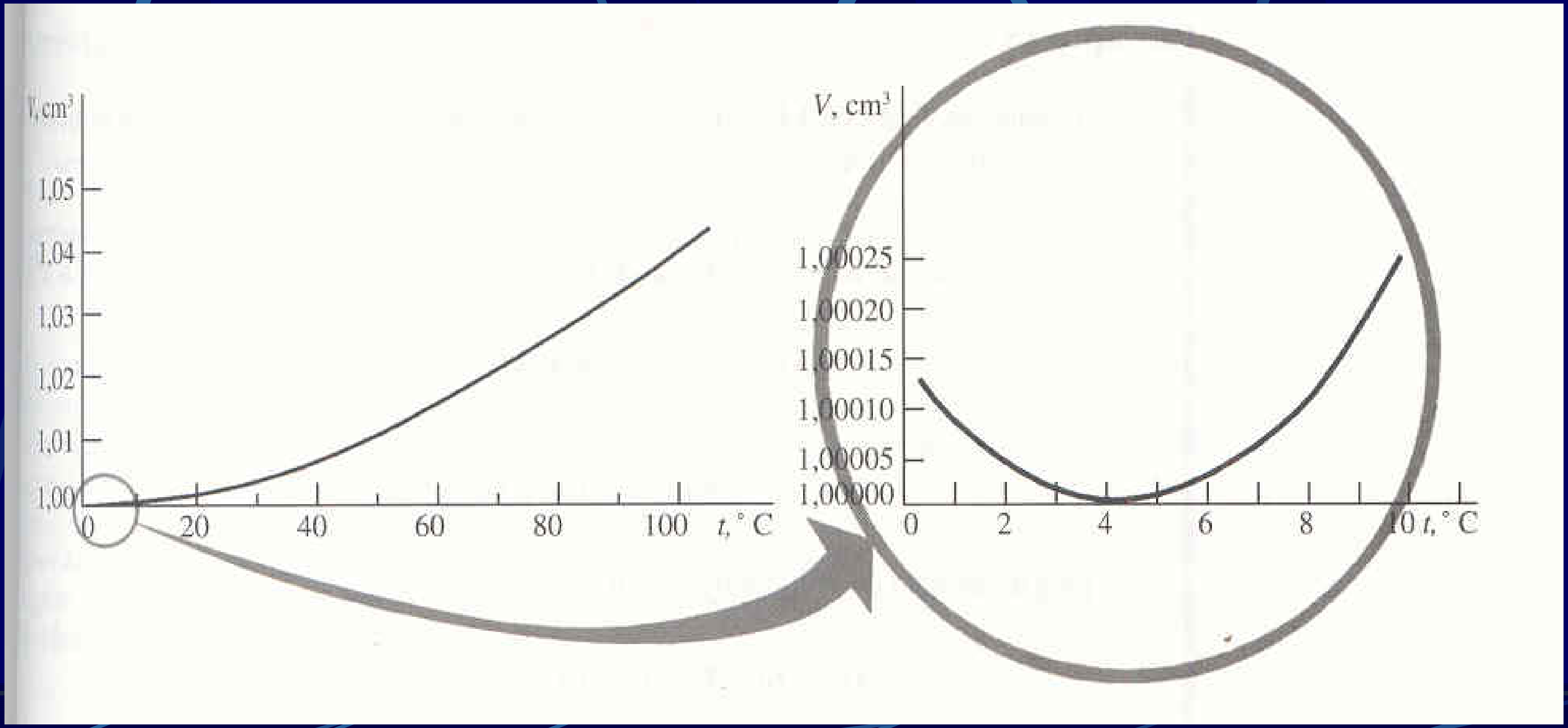
2.1. Theory

2.1.1. Surface Tension



2.1. Theory

2.1.2. Variation of the volume of 1g of water as a function of the temperature



2.1. Theory

2.1.3. Viscosity

Viscosity is an internal property of a fluid that offers resistance to flow.

Examples of products of high viscosity:

- Shampoo
- Syrup
- Oil

2.2. Methodology

- General view
- Analysis of parameters
- Analysis of dynamics

2.3. General view

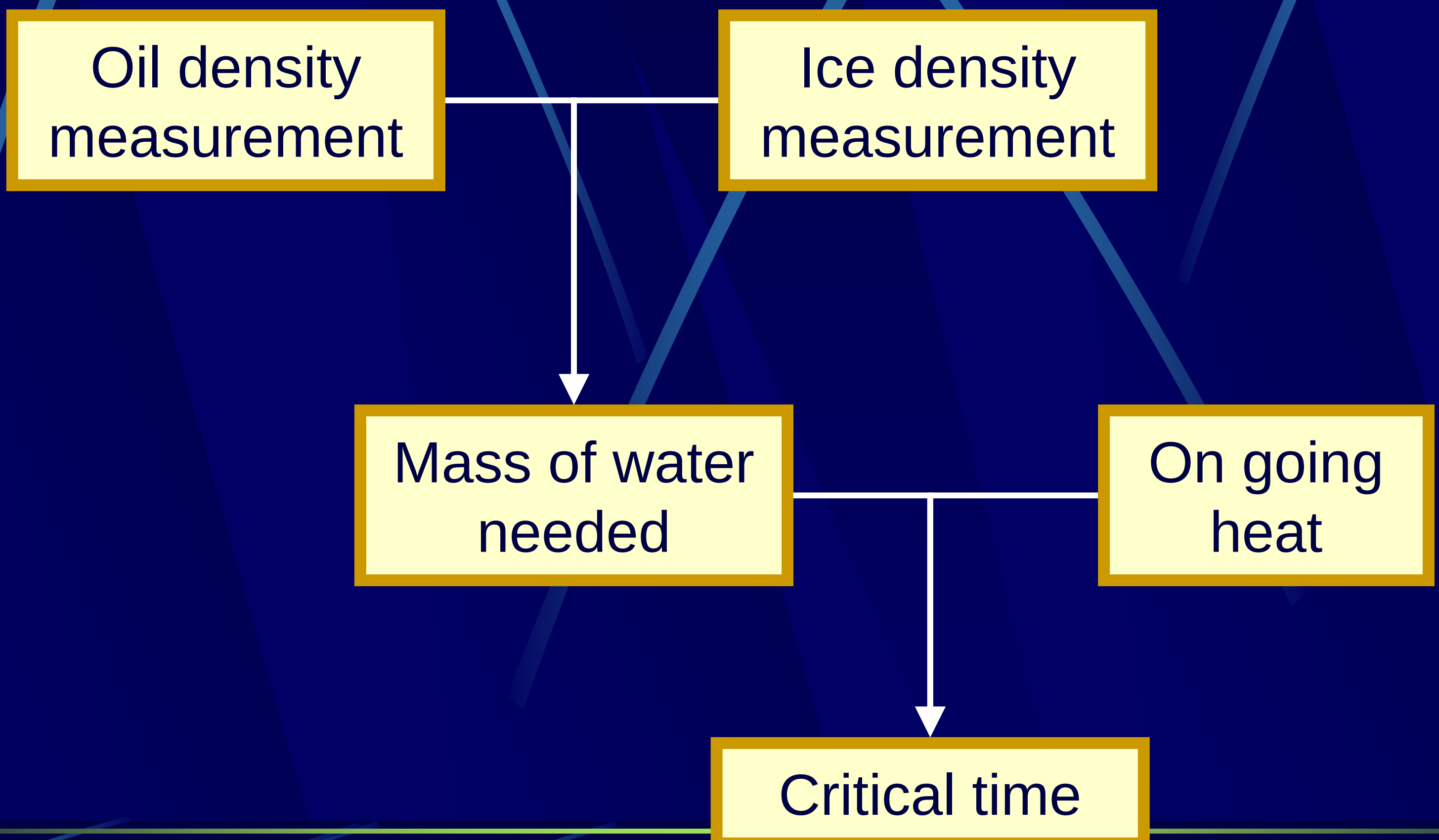
2.3.1. Analysis of the dynamics of the system (ice and water drop) – see tape 1

Three kinds of movement can happen

- Sinks → $d_g > d_0$
- Floats or oscillates → $d_g < d_0 < d_a$

2.4. Parameters

2.4.1. Strategy: conditions to oscillate

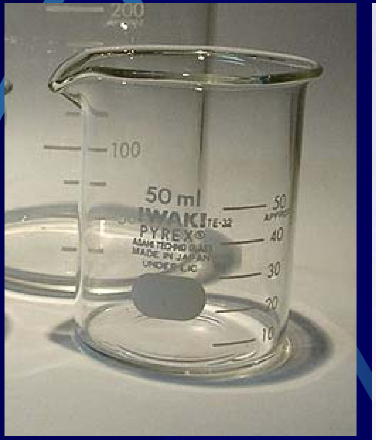


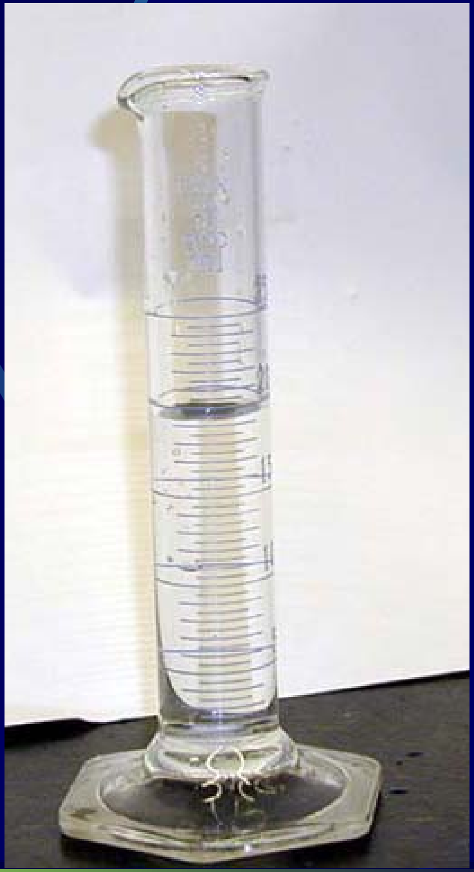
2.4. Parameters

2.4.1. Oil density measurement

2.4.1.1. Materials used

- Beakers
- Cylinder measuring
- Different kinds of oil
- Ice
- Scale





$6,602 \cdot 10^{-3}$

2.4. Parameters

2.4.1. Oil density measurement

2.4.1.2. mass of a 200ml of soya bean oil

Mass (g)	Volume (mL)	Density (g/ml)
184,6	200	0,923
183,7	200	0,9185
182,0	200	0,91

Average density:
0,917 g/mL

Error: $6,6 \cdot 10^{-3}$

67% probability

2.4. Parameters

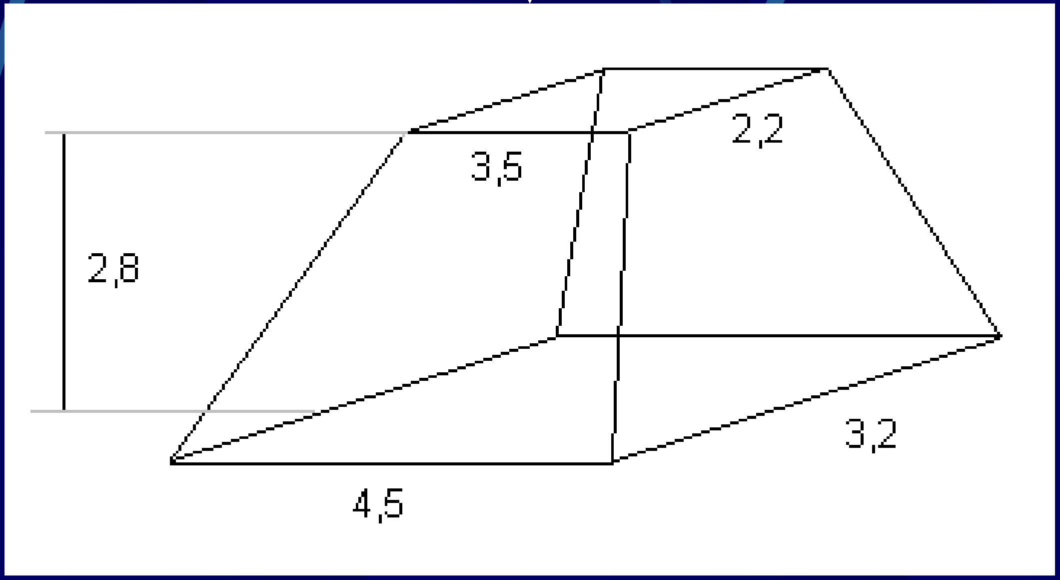
2.4.1. Oil density measurement

Oil	density (g/ml)
soya bean	0,913
canola	0,906
cotton	0,908
corn	0,916
sunflower	0,915
rice	0,913
olive	0,914
corn with vitamins	0,913

2.4. Parameters

2.4.2. Ice density determination

Ice shape



$V = 30,3\ cm^3$

$m = 27,3g$

$d = 0,9 g/cm^3$

2.4. Parameters

2.4.3. Mass of the drop necessary for the oscillation

$$d = \frac{m}{V} \Rightarrow d_s = \frac{(m_w + m_i) \cdot d_w \cdot d_i}{m_w d_i + m_i d_w}$$

System density as a function of the water and ice mass and density

d – density

m – mass

i – ice

w – water

s – system (ice and water drop)

2.4. Parameters

2.4.3 Mass of the drop necessary for the oscillation

$$d_s > d_o \rightarrow m_w > m_s \cdot \frac{d_w}{d_o} \cdot \frac{(d_o - d_i)}{(d_w - d_i)}$$

$$m_w = \frac{\Phi \cdot \Delta t}{L}$$

2.4. Parameters

2.4.4. On going heat

Materials used

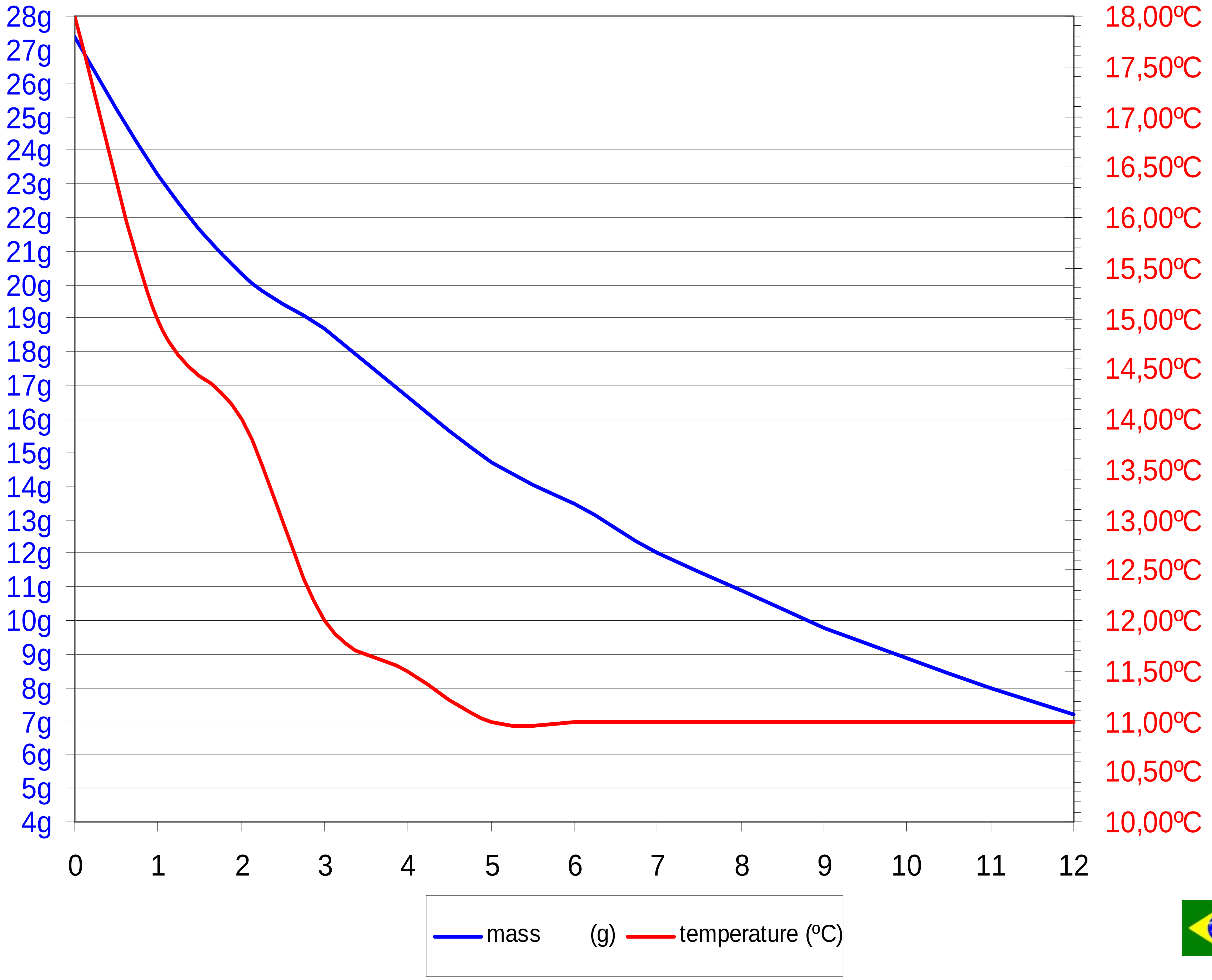
- Beakers
- Soya bean oil
- Ice
- Scale
- Chronometer
- Thermometer

2.4. Parameters

2.4.4. On going heat

Measurement of the mass of the ice through time

time (min)	mass (g)	temperature (ºC)
0	27,4	18
1	23,3	15
2	20,3	14
3	18,7	12
4	16,7	11,5
5	14,7	11
6	13,5	11
7	12	11
8	10,9	11
9	9,8	11
10	8,9	11
11	8	11
12	7,2	11


28g
27g
26g
25g
24g
23g
22g
21g
20g
19g
18g
17g
16g
15g
14g
13g
12g
11g
10g
9g
8g
7g
6g
5g
4g
18,00ºC
17,50ºC
17,00ºC
16,50ºC
16,00ºC
15,50ºC
15,00ºC
14,50ºC
14,00ºC
13,50ºC
13,00ºC
12,50ºC
12,00ºC
11,50ºC
11,00ºC
10,50ºC
10,00ºC
0
1
2
3
4
5
6
7
8
9
10
11
12
mass (g)
temperature (ºC)

$\Phi = 4{,}83\frac{cal}{s}$

2.4. Parameters

2.4.4. On going heat

$$\Phi = \frac{\Delta m \cdot L}{\Delta t}$$

$$\Phi = 4{,}83\frac{cal}{s}$$

- Φ - flux
- m - mass
- L - fusion heat
- t - time

$$\Delta m = 3{,}62\frac{g}{min}$$

Error: 0,426

67% probability

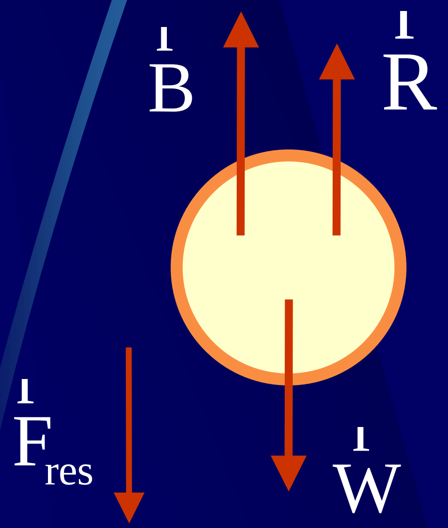
2.4. Parameters

2.4.5. Time before the first drop

$$t > m_s \cdot \frac{L}{\Phi} \cdot \frac{d_w}{d_o} \cdot \frac{(d_o - d_i)}{(d_w - d_i)} \rightarrow t \cong 35s$$

2.5. Dynamics

2.5.1. Dynamics of the oscillatory system before the first drop



$\vec{B}$ Buoyancy force

$\vec{W}$ Weight force

$\vec{R}$ Resistance force

$$\left|\vec{W}\right| = \text{constant} = mg$$

$$\left|\vec{B}\right| = d_0 \cdot V_S \cdot g$$

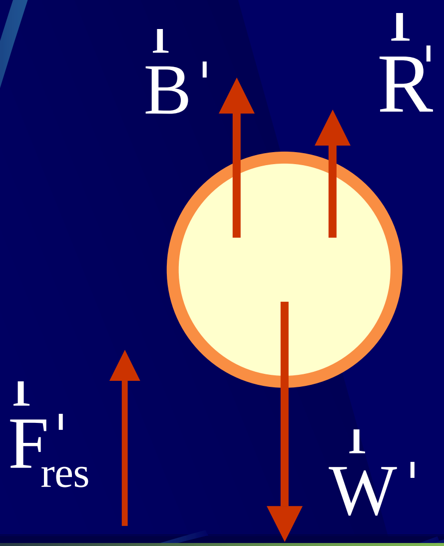
$$\left|\Delta\vec{B}\right| = \frac{\Phi \cdot \Delta t}{L} \cdot \left(\frac{d_i - d_w}{d_i \cdot d_w}\right) \cdot d_o \cdot g$$

$$\left|\vec{R}\right| = k \cdot v$$ → aproximation

$d_s \approx d_i$

2.5. Dynamics

2.5.2. Dynamics of the oscillatory system after the first drop



$W' \ll W$ $\quad m' \ll m$

$B' < B$ $\quad V' < V$

After the first drop

$$d_s \approx d_i$$

2.6. Error Analyses

<u>Experience:</u>

- Oil density measurement: air bubbles in the oil
- On going heat: the oil got stucked to the ice

<u>Devices:</u>

- Scale precision → 0,01 g
- Chronometer

2.7. Conclusions

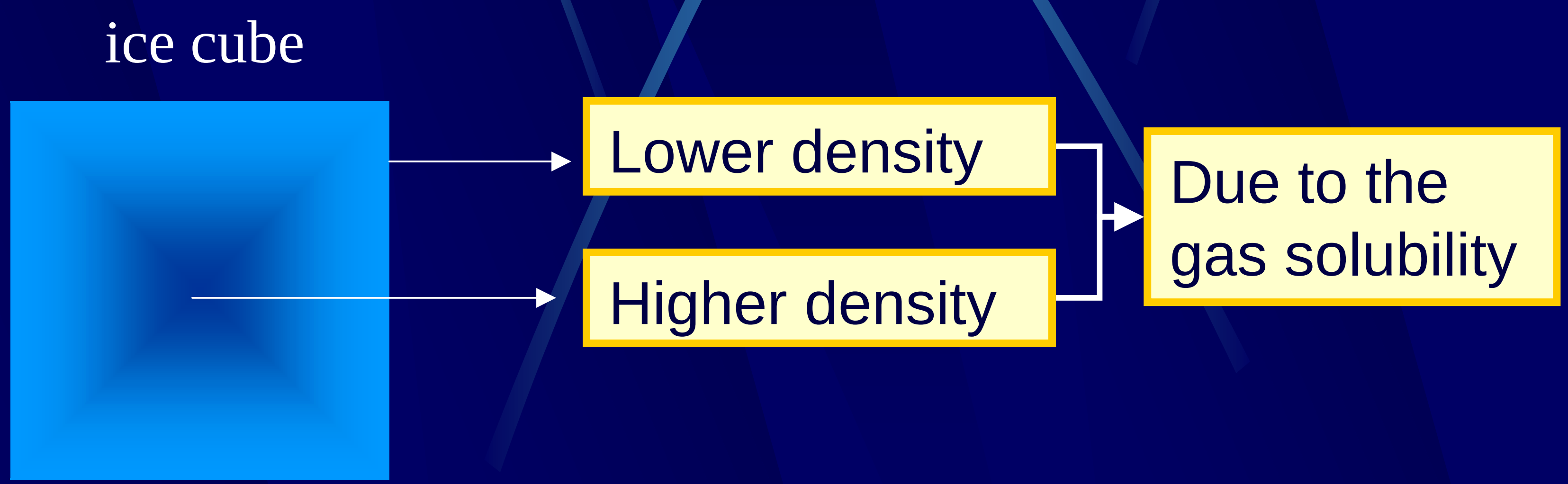
Most important factors:

- Format of the ice – determined the amount of water that the ice can support before the first drop

2.7. Conclusions

<u>Most important factors:</u>

- Ice non-constant density



2.7. Conclusions

<u>Most important factors:</u>

- Hydrogen bond – responsible for the density of water decrease under 4ºC (see graphic on slide 4)

- Surface tension – responsible for the formation of the water drops (soap experiment)

Apendix

Viscosity

$$\text{Viscosity} = \frac{[\text{Frictional Force x thickness x time}]}{[(\text{Area of plate}) \text{ x } (\text{distance})]}$$

Soya bean oil @ 20°C	69.3 cP
Water @ 99°C	0.2848 cP
Olive oil@ 20°C	84.0 cP
Honey @ 20°C	10.000 cP

[P] = Poise

Formulas

$$d = \frac{m}{v}$$

$$v = \frac{m}{d}$$

$$d_s = \frac{m_s}{v_s} = \frac{m_i + m_w}{v_i + v_w} = \frac{m_i + m_w}{\frac{m_i}{d_i} + \frac{m_w}{d_w}}$$

$$d_s = \frac{m_i + m_w}{\frac{m_i d_w + m_w d_i}{d_i d_w}} = \frac{(m_i + m_w) d_i d_w}{m_i d_w + m_w d_i}$$

Formulas

$$d_s > d_o$$

$$m_i = m_s - m_w$$

$$d_o < \frac{m_s d_i d_w}{m_s d_w - m_w d_w + m_w d_i}$$

$$m_s d_w d_o - m_w d_w d_o + m_w d_i d_o < m_s d_i d_w$$

$$m_w d_o (d_i - d_w) < m_s d_w (d_i - d_o)$$

$$m_w > m_s \frac{d_w}{d_o} \frac{(d_o - d_i)}{(d_w - d_i)}$$

Formulas

$$\phi = \frac{Q}{\Delta t}$$

$$Q = mL$$

$$\phi = \frac{mL}{\Delta t}$$

$$m = \frac{\phi.\Delta t}{L}$$

$$\frac{\phi.\Delta t}{L} > m_s \frac{d_w}{d_o} \frac{(d_o - d_i)}{(d_w - d_i)}$$

$$\Delta t > \frac{L}{\phi} m_s \frac{d_w}{d_o} \frac{(d_o - d_i)}{(d_w - d_i)}$$

Formulas

$$v = \frac{m}{d}$$

$$\Delta v = \frac{m}{d_w} - \frac{m}{d_i} = m\left(\frac{1}{d_w} - \frac{1}{d_i}\right)$$

$$\Delta v = m\frac{(d_i - d_w)}{d_w d_i}$$

Formulas

$$\phi = \frac{Q}{\Delta t}$$

$$Q = mL$$

$$\phi = \frac{mL}{\Delta t}$$

$$m = \frac{\phi.\Delta t}{L}$$

$$\Delta V = \frac{\phi.\Delta t}{L}\frac{(d_i - d_w)}{d_w d_i}$$

time

ΔV

Formulas

$$\vec{B} = V d_o g$$

$$\Delta \vec{B} = \Delta V d_o g$$

$$\Delta \vec{B} = \frac{\phi.\Delta t}{L} \frac{(d_i - d_w)}{d_w d_i} d_o g$$

$$\Delta V = \frac{\phi.\Delta t}{L} \frac{(d_i - d_w)}{d_w d_i}$$

2.1. Theory

2.1.3. Ice molecular structure

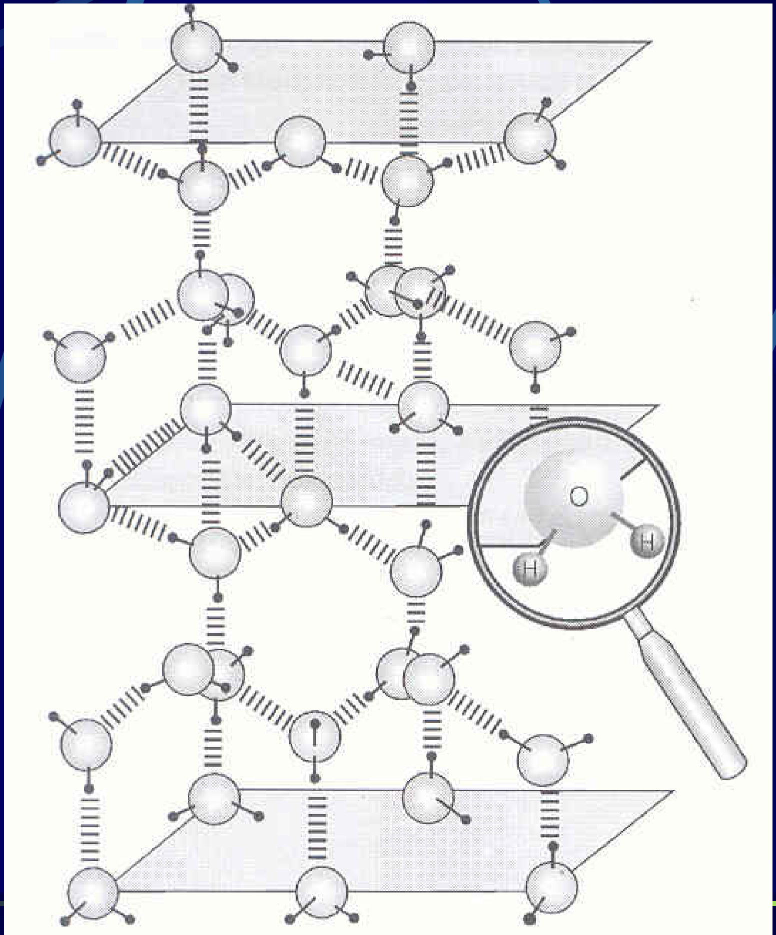
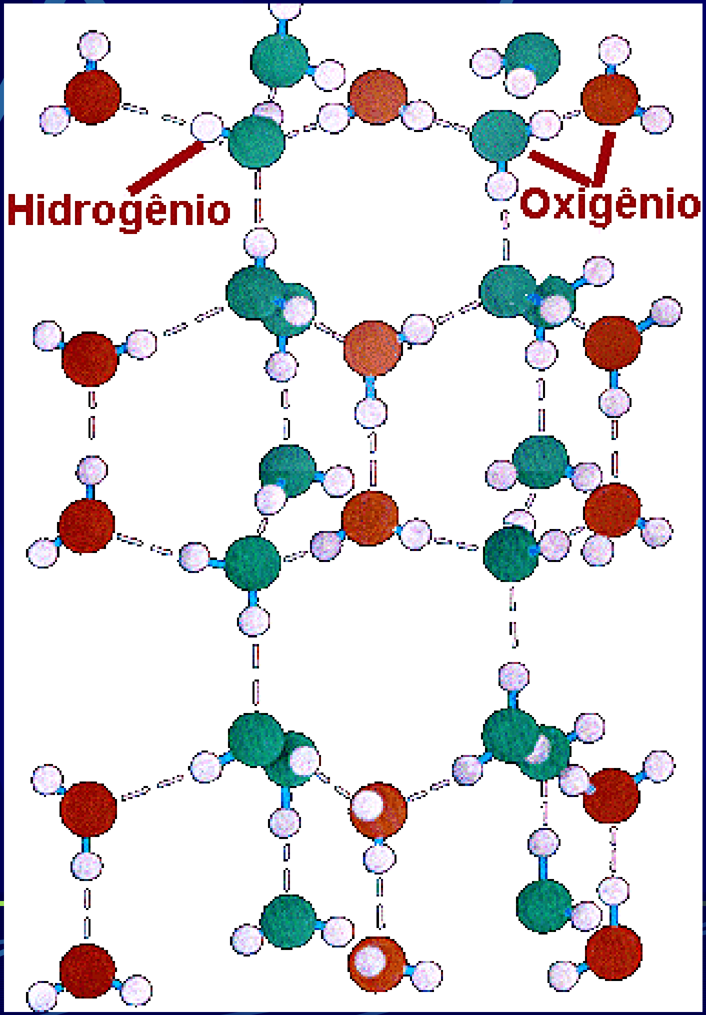


Figura 16: Estrutura tridimensional do gelo.



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