7. HEATED NEEDLE

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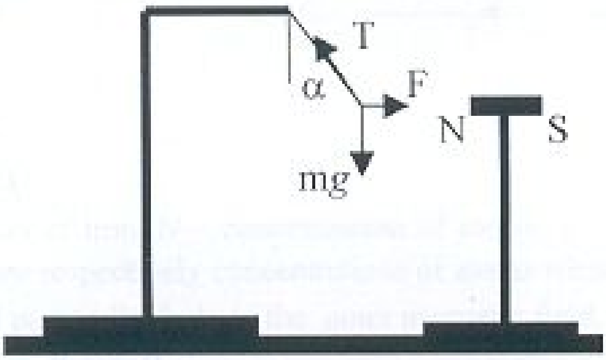
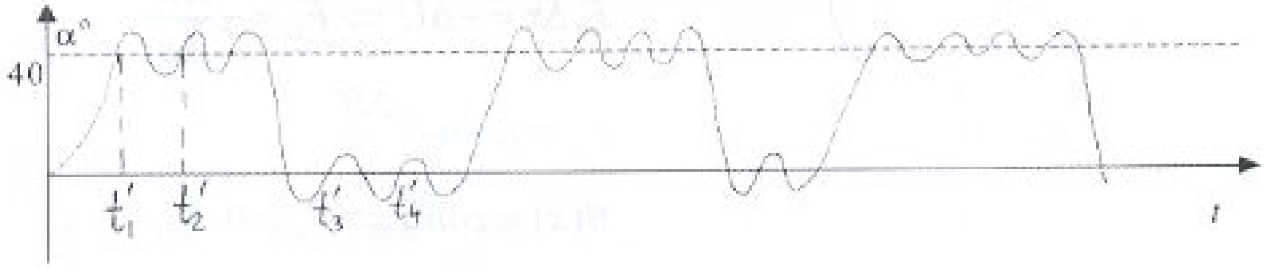
School № 42 named after I.N. Vekua

Experimental device



Experimental regimes



$$\alpha_0=40^0 \quad l_n=40\text{ mm}$$

$$\tau'_1=t'_2-t'_1\approx 0{,}43\text{ sec}$$

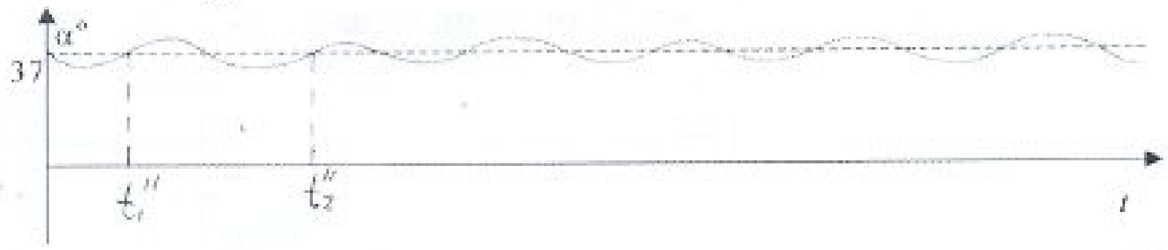
$$\tau'_2=t'_4-t'_3\approx 1\text{ sec}$$

$$F=mg\,\mathrm{tg}\,\alpha_0$$

$$\omega=\sqrt{\frac{\sqrt{F^2+(mg)^2}}{ml}}$$

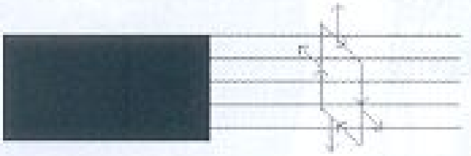
$$\tau=\frac{2\pi}{\omega}\approx 0{,}53$$

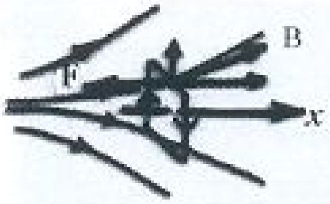
where l_n is length of needle, F is a magnet force, m is mass of needle and ω - frequency of oscilations near magnet.



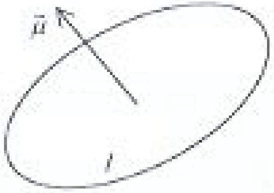
$$\alpha_0=37^0 \qquad \alpha_1=25^0 \qquad l_n=40\text{ mm}$$

IN CLASSICAL THEORY





$$\vec{\mu} = I\vec{s}$$



$$u = -\mu B \cos\vartheta \qquad \vartheta = (\vec{\mu}, \vec{B})$$

$$F_x \Delta x = -\Delta U \Rightarrow F_x = -\frac{\Delta U}{\Delta x}$$

$$F_x = \mu \cos\vartheta \frac{\Delta B}{\Delta x}$$

$$B(x) = const \Rightarrow F_x = 0$$

where μ is a magnet moment of circuit, I – current in the circuit, F_x – interaction force between circuit and magnet and S is square of the circuit.

From pictures and expression for F_x is clear that we have repulsion or attraction when magnetic field is not uniform

QUANTUM THEORY

$$\begin{cases} M = N < \mu > \\ N_{\uparrow\uparrow} = ae^{+\mu B/kT} \\ N_{\perp} \quad = a \\ N_{\uparrow\downarrow} = ae^{-\mu B/kT} \\ N = N_{\uparrow\uparrow} + N_{\uparrow\downarrow} + N_{\perp} \\ < \mu > = \dfrac{N_{\uparrow\downarrow}(+\mu\ ) + N_{\uparrow\uparrow}(-\mu) + 0 \cdot N_{\perp}}{N} \end{cases}$$

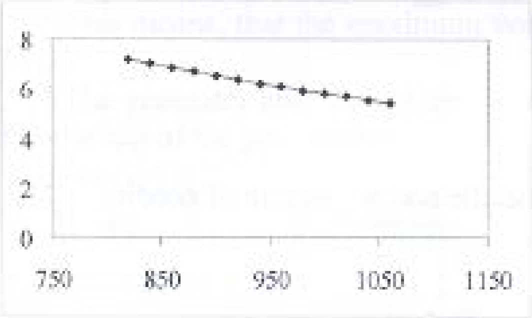
Probability is following:

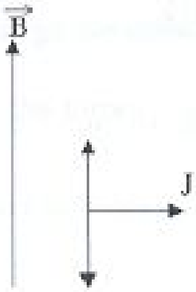
$$p \sim e^{-(\text{State energy})/kT}$$

$$B = \mu_0 \cdot (H_{out} + \omega \cdot M)$$

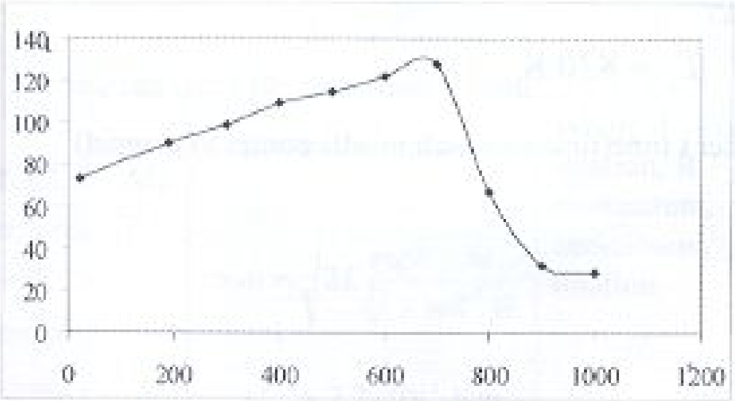
$$M = \mu N \frac{e^{-\mu B/kT} - e^{\mu B/kT}}{e^{-\mu B/kT} + e^{\mu B/kT} + 1}$$

where M is magnetization of iron, N – concentration of atoms, μ - magnetic moment of an atom, $N_{\uparrow\uparrow}$, $N_{\uparrow\downarrow}$, $N_{\perp}$ - are respectively concentrations of atoms whose magnetic moments are directed to, opposite and perpendicularly to the outer magnetic field,



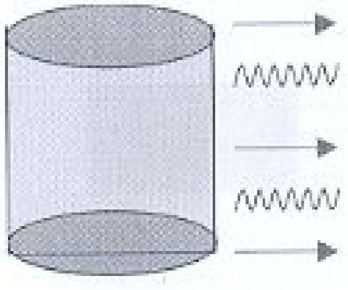


Dependence of magnetization on temperature



Dependence of coil inductivity on temperature of an iron core.

Thermodynamical calculations



For balance law we will get following expression:

$$-cm\,dT = \xi S(T - T_0)dt + \varepsilon\sigma S T^4 dt$$

$\xi \approx 20\ \mathrm{J/Ksm^2}$ $\varepsilon \approx 0{,}5$

$T_0 \approx 290\ \mathrm{K}$ $m \approx 0{,}15\ \mathrm{g}$

$S \approx 1{,}25\cdot 10^{-6}\mathrm{m}^2$ $c=460\ \mathrm{J/kg\cdot K}$

where T_0 is temperature of environment, m – mass of needle and S – square of needle.

$$-t\frac{S\varepsilon\sigma}{cm} = \int_{T_2}^{T_1} \frac{dT}{T^4 + \frac{\xi}{\varepsilon\sigma}T - \frac{\xi T_0}{\varepsilon\sigma}} \qquad t = 3s$$

$T_1 \approx 990\ \mathrm{K}$ $T_2 \approx 820\ \mathrm{K}$

T_1 and T_2 are respectively initial and after t time(time in which needle comes to magnet) temperatures.