Thermal and nonthermal noises in the suspension

(recent results of MSU group)

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The promise (Aug. 1998): LIGO II $\Rightarrow h \simeq 10^{-22}$, ($\frac{S}{N} = ?$ $\Delta f = ?$ $\tau_{AVER} = ?$)

The white papers (sept. 1999): LIGO II $\Rightarrow h_f \simeq 7 \times 10^{-24} \frac{1}{\sqrt{Hz}}$

$h \simeq 7 \times 10^{-23}$ for $\bar{f}_{grav} \simeq 10^{+2}$ Hz, $\Delta f \simeq 10^{+2}$ Hz

↑ Optimistic estimate based on the model of structural damping

? LIGO III $\Rightarrow h \simeq 10^{-23}$?

HOW SMALL THE DISSIPATION IN THE SUSPENSION HAS TO BE?

PESSIMISTIC model for pendulum mode ($H = const$)

$$F_{grav} = \frac{1}{2} h L \omega_{grav}^2 m \geq \frac{S}{N} \times \underbrace{\sqrt{4 k_B T H \frac{1}{\tau}}}_{FDT}$$

$h = 10^{-22}$, $L = 4 \times 10^5$ cm

$\omega_{gr} = 6 \times 10^2\ s^{-1}$, $m = 10^4$ gram

$\frac{S}{N} = 5$, $T = 300$ K, $m \simeq 10^{+4}$ gram

$\tau = 10^{-2}$ sec

$$F_{grav} \simeq 8 \times 10^{-8} \text{ dyn}$$

$$\tau_M^* = \frac{m}{H} \simeq 6 \times 10^{+8} \text{ sec} \simeq 20 \text{ years}$$

Quantum „remark"

$$h_{SQL} = \sqrt{\frac{\frac{2\hbar\tau}{m}}{L^2}} \simeq 7\times10^{-23} \quad \text{FOR } \tau = 5\cdot10^{-3}\,s,\ m = 10^4\,\text{gram},\ L = 4\cdot10^5\,\text{cm}$$

TWO PIN TYPE MEASUR. OF COORDINATE

STANDARD QL
NAIVE QL
STUPID QL

There is no rigorouse formula for Δt

$$h_{SQL} \simeq \sqrt{\frac{4\hbar}{L^2 m\,\omega^2\tau}} \simeq 2.5\times10^{-23} \quad \text{FOR } \tau\omega \simeq 1,\ \omega = 6\cdot10^{+2}\,\frac{\text{rad}}{\text{sec}}$$

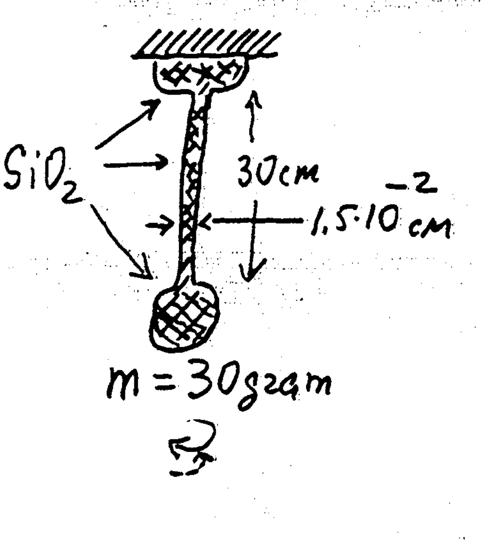
IF $\omega\tau \gg 1$

$$\frac{2\kappa T\tau^2}{\tau^*_M} \Rightarrow \tau^*_M \simeq \frac{2\cdot4\cdot10^{-14}\cdot(5\cdot10^{-3})^2}{10^{-27}} \simeq 2\times10^{9}\,\text{sec} \simeq 60 \text{ years}$$

Brief „history" of MSU efforts ($t \geq 1991$)

INITIAL KNOWLEDGE: $\left(Q_{\substack{\text{PURE}\\ SiO_2}}\right)_{\text{INTRINSIC}} \simeq 2\times10^{+7}$

I. Torsional mode

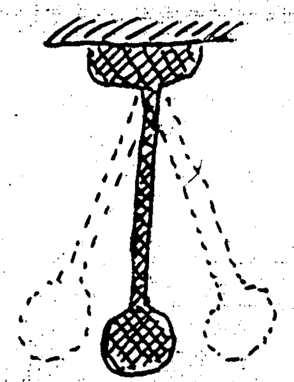


$$\omega_M \simeq 1.1\ \frac{\text{rad}}{\text{sec}}$$
$$\tau^*_M \simeq (1.2\pm0.1)\times10^{7}\,\text{sec}$$
$$Q_M \simeq 7\times10^{6}$$

FIRST EVIDENCE OF THE SURFACE LOSSES

JETP LETT. v.55 (1992) 432

II Pendulum mode



$m = 30$ gram

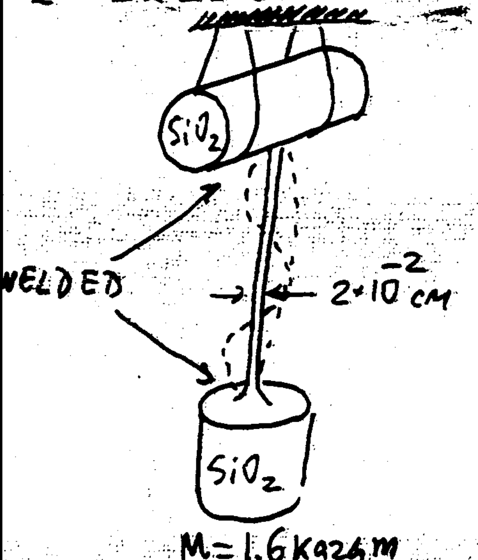
$\omega_M \simeq 5.5 \ \frac{rad}{sec}$

$\tau^*_M \simeq 4.4 \times 10^{+7}$ sec $\simeq 1.5$ year

$Q \simeq 1{,}3 \times 10^{+8}$

PHYS. LETT. A v 175 (1993), 82

III VIOLIN MODES



$Q_{BENDING\ MODES} \simeq 10^6 - 5 \times 10^6$ (NO 1.6kg mass)

ANOTHER EVIDENCE OF SURFACE LOSSES

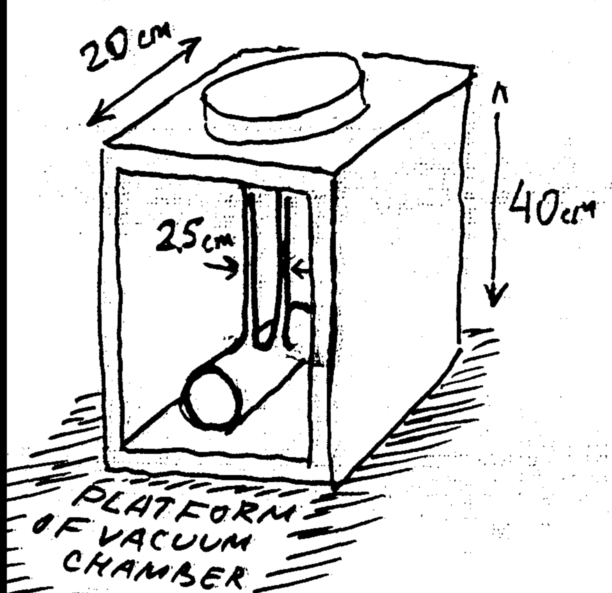
$\omega_{VIOLIN} \simeq 2\pi \left(1 \times 10^{+3} - 5 \times 10^{+3}\right) \frac{rad}{sec}$

$Q_{VIOLIN} \simeq 1 \times 10^{+7} - 1 \times 10^{+8}$

sufficient to reach $h < 10^{-22}$

PHYSICS DOKLADY v. 345 (1995), 324

IV TORSIONAL-PENDULUM MODE (LOWER FREQUENCY ⇒ LOWER RECOIL LOSSES)



$m = 2$ kg

$\omega_M \simeq 2 \ \frac{rad}{sec}$

$\tau^*_M \simeq 1 \times 10^{+8} \pm 10\% \simeq 3$ YEARS

$Q_{T-P} \simeq 1 \times 10^{+8}$

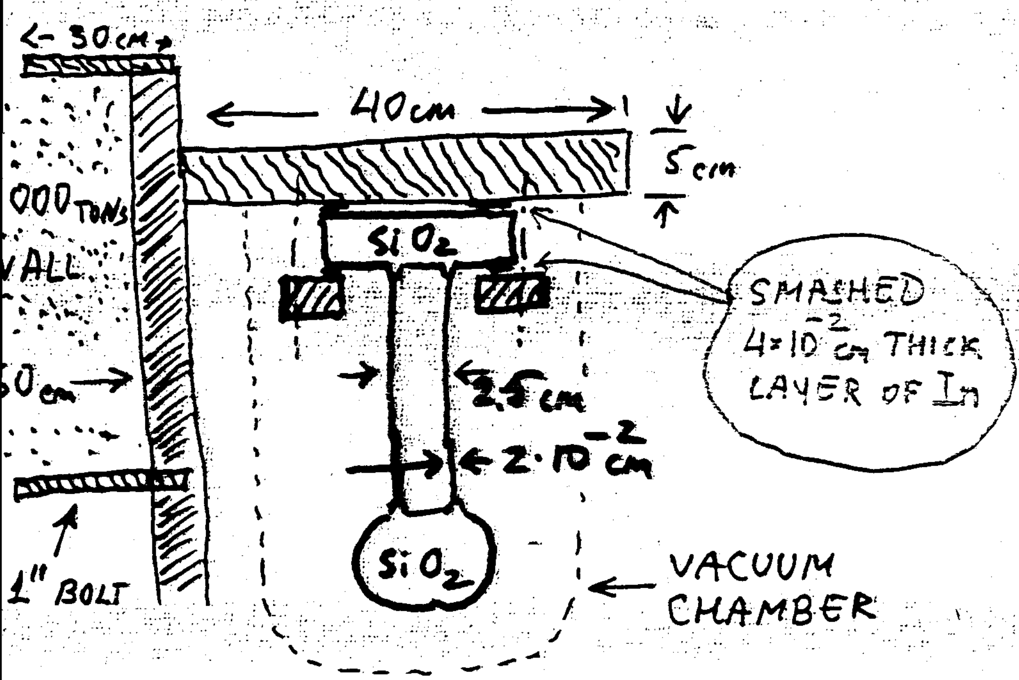
$Q_{expected} \simeq 10^{+9}$

(SEE BELOW)

PHYS. LETT. A v 218 (1996), 164.

V TORSIOLAL-PENDULUM MODE (SECOND ATEMPT)

1) LOWER RECOIL LOSES
2) BETTER VACUUM
3) ENFORSED VENTILATION VIA DUST ABSORBER (1-2 orders less dust?)
4) SHORTER TIME BETWEEN THE MANUFACTERING OF THE FIBER AND THE INSTALLATION INTO THE CHAMBER
5) BACKING (100°-120°C).



THE RESULTS:

$m = 2$ kg (ETHED PINS)

$\omega_M = 2\pi \times 0.34$ rad/sec

$\tau^*_{T-P} \simeq 1.86 \times 10^{+8}$ sec $\simeq$ 6 YEAR

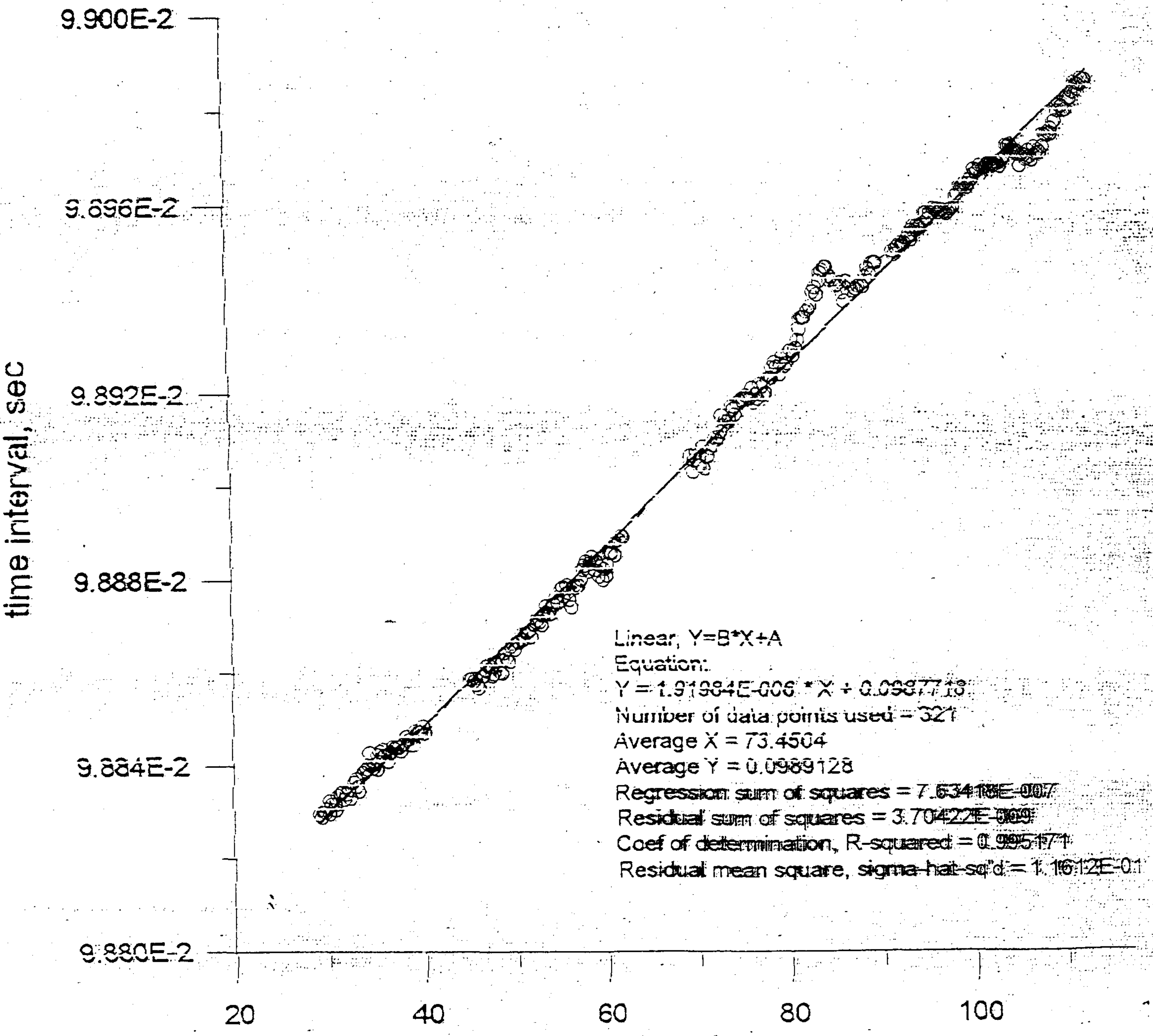
$Q_{T-P} \simeq 2 \times 10^{+8}$

$m \simeq 0.5$ kg (J. HOUGH ET AL BONDED PINS)

$\omega_M \simeq 2\pi \cdot 1.17$ rad/sec

$\tau^*_{T-P} \simeq 6.3 \times 10^{+7}$ sec $\simeq$ 2 YEARS

$Q_{T-P} \simeq 2.3 \times 10^{+8}$



V.P. MITROFANOV, K.Y. TOKMAKOV

$\tau^*_M \simeq 1.86 \times 10^{+8}$ sec $\simeq$ 6 years, $Q_M \simeq 2 \times 10^{+8}$, March 2nd, 1998

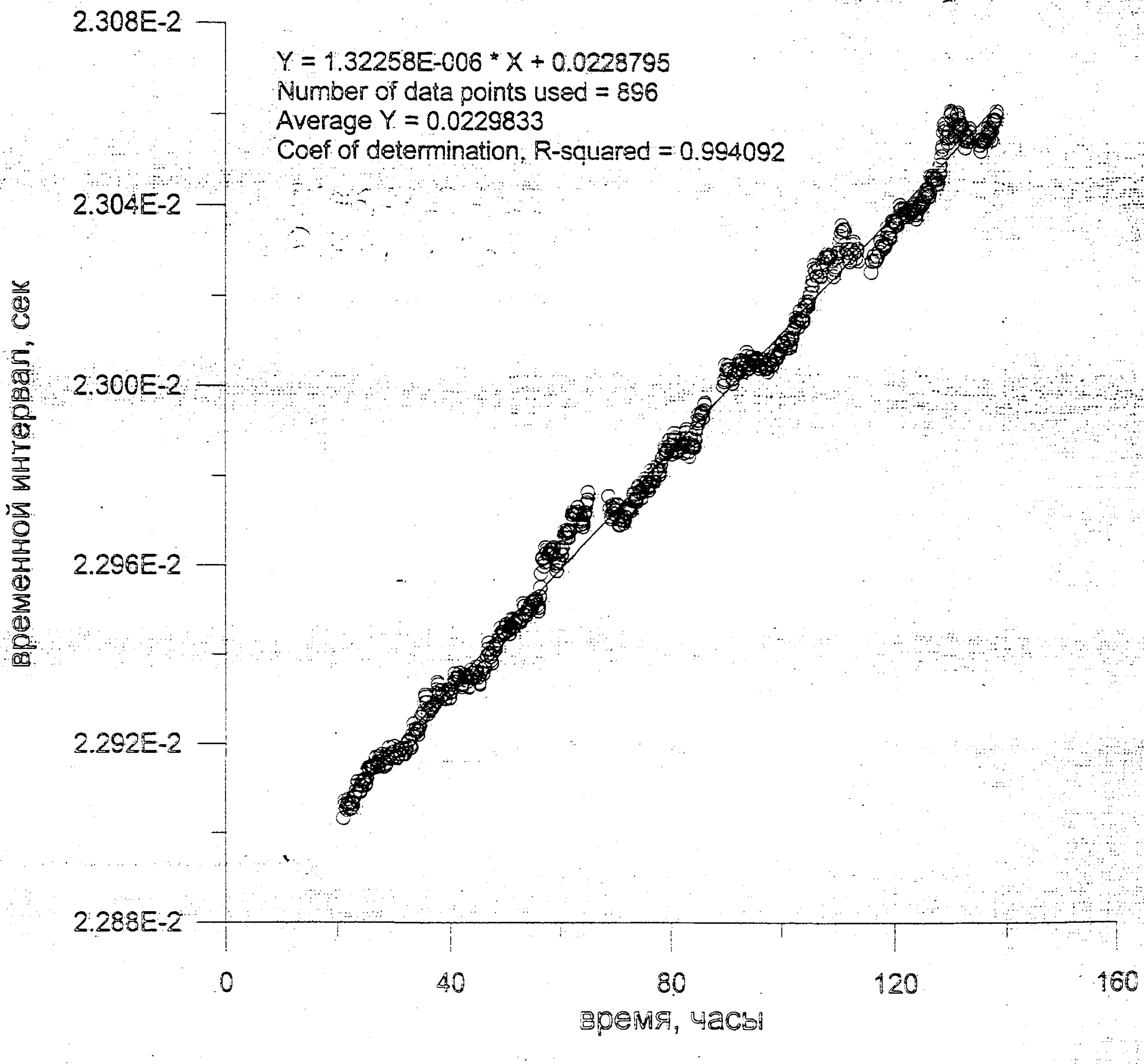
$$\tau^* = \frac{9.9 \cdot 10^{-2}}{1.92 \cdot 10^{-6}} \cdot 3600 = 1.86 \cdot 10^{8}$$

21. MAY, 1999

V. P. MITROFANOV, K. V. TOKMAKOV

$\tau_M^* = 6.3 \times 10^7$ sec, $Q_M = 2.3 \times 10^8$

(JIM HOUGH GLUED SUSPENSION)



The comparison with the "theory"

$$Q^{-1}_{T-P} \simeq \frac{\pi G r^4}{m g a^2}\phi_G + \frac{1}{\ell}\sqrt{\frac{\pi Y r^4}{2 m g}}\phi_Y$$

$G = 3\times10^{11}\ \frac{dyn}{cm^2}$ $a = 2.5\,cm$
$Y = 7\times10^{11}\ \frac{dyn}{cm^2}$ $r = 1\times10^{-2}\,cm$
$m = 2\times10^{+3}\,gram$ $\ell = 25\,cm$

$+\ \phi_G = \phi_Y = 1.4\cdot10^{-7}$ FROM EXPERIMENT

$(Q_{T-P}) \simeq 2\times10^{+9}$ EXPECTED

POSSIBLE EXPLANATIONS $[(Q_{T-P})_{MEASUR} \simeq 2\times10^{+8}]$

1. Nonperfect isolation (recoil losses), In?
2. Nonsufficient backing (mud on surface: $H_2O + SiO_2$)
3. Additional losses on the pins (rough surface + sedimentation)
4. Dust particles (16 particles detected by a torch in "postmortal" examination of the fiber)

THE RESERVES (SEE THE FORMULA ABOVE)

1. $\frac{G_F}{Y} = 4\times10^{-3}$ IN THE MEASURMENTS, BUT "VIRGIN" FIBERS ACCEPT $G_F/Y \simeq (2-3)\times10^{-2}$! (O.A. Okhrimenko)
2. $r^4 \to ab^3$ (ribbon) $\to$ may give factor 3–6 for Q
3. $\ell = 25\,cm \Rightarrow \ell = 250\,cm.$

$\longrightarrow$ $Q \simeq 10^{10}$ IS NOT A CRAZY NUMBER (IF ONE HAS ENOUGH MONEY AND PATIENCE)

STRATEGIC RESERVE: THE SUBSTRACTION OF BROWNIAN MOTION: "HOW TO REDUCE THE SUSPENSION THERMAL NOISE WHITHOUT IMPROVING THE Q's IN THE PENDULUM AND VIOLIN MODES": 2 orders (GR-QC/9805031)

The problem of the nonthermal noise (excess noise)

(FDT is a big illusion)

An assumption:

Probably (?) the main source of nonthermal noise is very stressed wire (fiber) in the suspension.

The results:

1) The tungsten wires are very noisy (strong excess noise above the thermal one) even when $\sigma_{Appl}/\sigma_{Break} \simeq 0.3$

(Phys. Lett. A 227 (1997), 159)

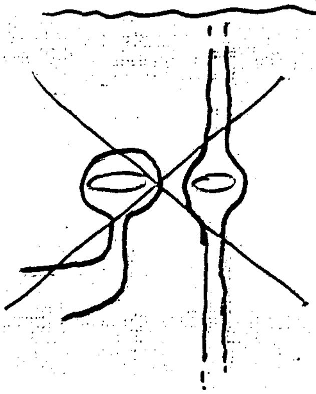
2) The steel wires are (5-8) times less noisy then the tungsten ones, but if $\sigma_{appl}/\sigma_{Break} \simeq 0.3$ this noise may mimic $h \simeq 5 \cdot 10^{-21}$

$\sqrt{\overline{\Delta X^2_{THERM}}} \simeq 2 \cdot 10^{-10}$ cm, $\Delta X_{METER} \simeq 2 \times 10^{-11} \frac{cm}{\sqrt{Hz}}$

(Phys. Lett. A 246, (1998), 479)

NOISE IN SiO_2 FIBERS?

The goal is $\Delta X_{meter} \simeq 10^{-13} \frac{cm}{\sqrt{Hz}}$ and do not damage the VIRGINITY of the SiO_2 fiber ($t \simeq 1999, 2000$)



THIS VERSION OF METER FAILED

new version of meter is in process of assemling. If our calculations are correct then $\Delta x \simeq 1 \times 10^{-15} \frac{cm}{\sqrt{Hz}}$ and the VIRGINITY will not be damaged