NONLINEAR LOW-TEMPERATURE ABSORPTION OF ULTRASOUND AND ELECTROMAGNETIC WAVES IN GLASSES

Yu.M.Galperin

A.F.Ioffe Physical-Technical Institute, Leningrad, USSR

D.A.Parshin

M.I.Kalinin Polytechnical Institute, Leningrad, USSR.

and

V.N.Solovyev

State Pedagogical Institute, Krivoy Rog, USSR.

Our aim is to consider nonlinear absorption of ultrasonic (or electromagnetic) waves by two-level systems (TLS's) in glasses. We are interested in the relaxational contribution to the absorption (the resonant one, if present, saturates at very low intensity of the wave).

The nonlinear behaviour of relaxational absorption is determined by the ratio $u=d/kT$ where d is the amplitude of modulation of the interlevel spacing E by wave:

$$E(t) = [(\Delta + d\cos\omega t)^2 + \Delta_0^2]^{1/2} \qquad (1)$$

Here Δ is asymmetry while Δ_0 being the tunnel integral; at $d \to 0$, $E(t) \to E_0 = [\Delta^2 + \Delta_0^2]^{1/2}$.

If $u \gg 1$ the absorption coefficient α is strongly nonlinear. According to the Ref's [1-3], in this regime α decreases with increase of u both in dielectric and metallic glasses. Here we want to consider the case of weak nonlinearity where $u \ll 1$ and nonlinear contributions are much smaller than the linear one. The aim is to determine the magnitude of the nonlinear contribution and its sign.

To analyse the qualitative picture let us evaluate the linear contribution to the absorption - dp_0 of the TLS from the interval (E, E+dE) at $E \ll kT$:

$$dp_0 \backsim \frac{\omega^2\tau}{1 + (\omega\tau)^2} dE \qquad (2)$$

where $\tau = \tau(E,\Delta_0)$ can be expressed in the form

$$1/\tau = (\Delta_0/kT)^2/\tau_0(x), \qquad x = E/kT.$$

In dielectric glasses $\tau_0(x)$ is independent of x and equal to $\tau_{0D} \backsim T^{-3}$ while in metallic ones $1/\tau_0(x) = x^{-2}/\tau_{0M}$ where $\tau_{0M} \backsim T^{-1}$. To calculate the contribution of the

TLS's with $E < E^* < kT$ one should average Eq.(1) over τ and integrate over E between 0 and E^*. Assuming that $\log(\Delta_0)$ is uniformly distributed we come to the distribution function $P(\tau)$ which is up to the first approximation equal to $1/\tau$ ($\tau > \tau_{MIN} \equiv \tau(E, \Delta_0=E)$). As a result, we have

$$\Delta P_0 \backsim \int_0^{x^*} dx \, \tan^{-1}\left[\frac{x^2}{\omega\tau_0(x)}\right] \qquad (3)$$

Now let us obtain rough estimates of the nonlinear corrections. Assuming

$$(p-p_0)/p_0 \simeq (d/E)^2 = (d/kT)^2 x^{-2}$$

we get

$$p_{NL} = P - P_0 \simeq \left(\frac{d}{kT}\right)^2 \int_0^{x^*} \frac{dx}{x^2} \left(\frac{1}{x^2}\right) \tan^{-1}\left[\frac{x^2}{\omega\tau_0(x)}\right] \qquad (4)$$

In metallic glasses the ratio $x^2/\omega\tau_0(x) = \text{const}$ and integral (4) diverges at its lower limit. This means that the nonlinear contribution is determined by low energies, $E \ll kT$, where one cannot expand all the quantities in powers of d/E.

In dielectric glasses the result depends on the product $\omega\tau_{0D}$. At $\omega\tau_{0D} \gg 1$ the Eq.(4) is determined by its upper limit. It means that the energies of the order of kT are important. One can show that in this case the nonlinear contribution is negative and proportional to $(d/kT)^2$.

If $\omega\tau_{0D} \ll 1$ a new characteristic energy $E_1 = kT(\omega\tau_{0D})^{1/2} \ll kT$ appears. If this energy is much larger than d one can also expand all the quantities in powers of d/E. The relative nonlinear contribution in this case is positive and of the order of $(d/E_1)^2 \gg (d/kT)^2$. At $E_1 \ll d$ one faces the same situation as in metallic glasses, i.e. the TLS's with $E < d$ are of the most importance. In this situation the nonlinear contribution for these TLS's is of the order of unity and the relative nonlinear contribution to the absorption is of the order of relative number of the TLS's with $E < d$ and $d \ll E < kT$, i.e. is of the order of $|d|/kT$.

The same holds for metallic glasses; one can show that in these cases the nonlinear contribution is negative. To determine the sign of the nonlinear contribution and to

calculate the numerical factors in the abovementioned estimates one should use the exact expression for the power absorbed by a TLS (see [1-3]):

$$p = \langle n\dot{E} \rangle = \left(\frac{\omega}{2\pi}\right) \int_0^{2\pi/\omega} dt\, n(t)\left(\frac{dE}{dt}\right) \tag{5}$$

where the occupation numbers $n(t)$ are determined from the equation $(dn/dt) = (n-n_0)/\tau$, and $n_0 = [1 + \exp(E/kT)]^{-1}$.

It is important that due to adiabatic approximation it is the quantity $E = E(t)$ from Eq.(1), rather than $E = E_0$ that is present in every place in the expressions for $\tau(E, \Delta_0)$ and n_0. This point leads to contradiction between our results and the results obtained by Levelut & Schon [4]. The coefficients obtained by us are given in the Table.

Table.

Values P^{xl}/P_0 in different limiting cases ($d \ll kT$).

Material	Parameters	P^{xl}/P_0
Metallic glasses	$\omega\tau_{0M} \gg 1$	$-0.5(|d|/kT)$
	$\omega\tau_{0M} \ll 1$	$-a(|d|/kT)$
Dielectric glasses	$\omega\tau_{0D} \gg 1$	$-0.3(d/kT)^2$
	$1 \gg \omega\tau_{0D} \gg (d/kT)^2$	$+0.05(d/kT\sqrt{\omega\tau_{0D}})^2$
	$\omega\tau_{0D} \ll (d/kT)^2$	$-0.2(|d|/kT)$

The coefficient a in the second row of the table seems to be positive. The value of $|a|$ is small and we have not succeded in its determination with enough accuracy.

We want to emphasize that the simple procedure of expansion of the absorption coefficient in powers of the wave intensity fails in metallic glasses, as it is clear from the Table given above.

References

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