An experimental investigation of the mechanical behavior of a number of polymers in the
range 4.2-240°K has been made. It has been shown that at helium temperature the Poisson
ratio is governed by the free volume. It has been established that the dynamic Young's
modulus and shear modulus of these polymers at 4.2°K depend on the chemical structure:
their values are determined by the mean distance between neighboring macromolecule
chains.

Previous experimental research on the mechanical behavior of polymer materials has been conducted
mainly with a torsion pendulum (frequency ~ 1 Hz) [1, 2] or by means of the Bordoni method (~10^4 Hz) [3].

All the polymers investigated have exhibited a monotonic increase in the dynamic moduli, both at ~1
and ~10^4 Hz, up to 4.2°K with a decrease in temperature; to a certain extent this might be due to the mo-
bility of small kinetic elements, which at such low frequencies (~1 and 10^4 Hz) make a contribution to the
mechanical behavior of polymers at helium temperatures.

From this point of view it is of great interest to compare the moduli measured at various frequencies
differing by several orders of magnitude. Such a comparison cannot be performed from published reports
because the dynamic shear modulus has been measured at lower frequencies (~1 Hz) and the dynamic
Young's modulus at higher frequencies (~10^4 Hz).

Note that the literature does not give information on the temperature dependences of the dynamic
modulus of uniform compression and the Poisson ratio of polymers at helium temperatures. It is there-
fore necessary to conduct research enabling us to determine the temperature dependences of the Poisson
ratio, the Young's modulus, and the shear modulus simultaneously at several frequencies.

We used such a method based on an investigation of the rate of propagation of longitudinal and shear
ultrasonic waves in polymers at frequencies of several megahertz. The measurements were performed
at 1 and 5 MHz in the range 4.2-240°K. We used the pulse-phase compensation method [4]; the relative
error of measurement of the speed of sound, assessed from the experimental scatter, was not more than
0.5%. Thermostatic control and thermal regulation of the specimen were effected by an automatic tempera-
ture regulator [5] to within ±0.1°K. The temperature dependences of the Poisson ratio \( \sigma \), Young's modulus \( E' \),
and shear modulus \( G' \) were calculated from the equations

\[
\sigma = \frac{c_l^2 - c_s^2}{2(c_l^2 - c_s^2)}; \quad E' = \frac{\rho c_l^2(1 - 2\sigma)(1 + \sigma)}{(1 - \sigma)}; \quad G' = \frac{\rho c_s^2}{2},
\]

where \( c_l \) is the speed of the longitudinal waves as a function of temperature, \( c_s \) is the speed of the shear
waves, and \( \rho \) is the density of the polymer.

We investigated the effect of chemical structure on the temperature dependences of these polymer
parameters.

The investigation was performed on specimens of high-pressure and low-pressure polyethylene (HPPE
and LPPE, respectively), polytetrafluoroethylene (PTFE), polytrifluoroethylene (PTFCE), copolymers
TABLE 1. Dynamic Moduli of Polymers

<table>
<thead>
<tr>
<th>Polymer</th>
<th>4.2°K</th>
<th>293°K</th>
<th>Low-frequency moduli at 4.2°K</th>
<th>Theoretical modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$E'$</td>
<td>$G'$</td>
<td>$E'$</td>
<td>$G'$</td>
</tr>
<tr>
<td>POM</td>
<td>14.26</td>
<td>5.44</td>
<td>7.13</td>
<td>2.75</td>
</tr>
<tr>
<td>PE</td>
<td>10.83</td>
<td>3.74</td>
<td>3.5</td>
<td>1.1</td>
</tr>
<tr>
<td>PTFE</td>
<td>7.85</td>
<td>3.04</td>
<td>2.97</td>
<td>1.15</td>
</tr>
<tr>
<td>PTFCE</td>
<td>6.52</td>
<td>2.38</td>
<td>4.13</td>
<td>1.42</td>
</tr>
<tr>
<td>CTFE</td>
<td>7.49</td>
<td>2.71</td>
<td>2.86</td>
<td>1.03</td>
</tr>
<tr>
<td>CTVF</td>
<td>8.03</td>
<td>2.91</td>
<td>2.62</td>
<td>0.92</td>
</tr>
<tr>
<td>PP</td>
<td>7.33</td>
<td>2.75</td>
<td>4.24</td>
<td>1.6</td>
</tr>
<tr>
<td>ÉD-5</td>
<td>6.04</td>
<td>2.21</td>
<td>3.68</td>
<td>1.26</td>
</tr>
<tr>
<td></td>
<td>8.54</td>
<td>3.21</td>
<td>6.04</td>
<td>2.15</td>
</tr>
</tbody>
</table>

*Calculated from measurements of the shear modulus taking a Poisson ratio of 0.3.

Fig. 1. Temperature dependences of Poisson ratio (a), dynamic Young's modulus (b), and shear modulus (c): 1) HPPE; 2) LPPE; 3) PTFE; 4) PTFCE; 5) CTFE; 6) CTVF; 7) POM; 8) PP; 9) PC; 10) ÉD-5.

From an analysis of the ($\sigma$, $T$) curves of Fig. 1a, we can infer that HPPE, which has the simplest chemical structure, has the lowest Poisson ratio at 4.2°K.

Since $\sigma$ tells us the extent of transverse compression under longitudinal extension, it is evident that this parameter is governed to a certain degree by the "free volume" of the polymer. On this basis we must