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LXX. The mechanical vibration of atoms
William Sutherland
Melbourne
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The Mechanical Vibration of Atoms.

(2) For the middle octaves of the pianoforte, when these two halves have a natural pitch near the pitch of the strings exciting them, a resonance takes place and a good musical tone results.

(3) For the two lower octaves the statement in (2) does not apply.

(4) Strong 2nd and 3rd partials are detrimental to good musical tone.

14 City Road, London, E.C.
June 17, 1910.

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LXX. The Mechanical Vibration of Atoms.
By William Sutherland*.

On account of the electric origin of rigidity and of cohesion, both within and without the atom, there is no real distinction between the mechanical and the electrical vibrations of atoms, but it is convenient to distinguish as mechanical vibrations those which can be calculated without directly considering the electrical properties of an atom.

The experimental researches of Rubens and his collaborators, Aschkinass, Nichols, and Ladenburg, have carried the measurements of wave-lengths into extreme regions of the infra-red spectrum, where the period of vibration is getting quite close to the order of magnitude to be expected from the mechanical vibrations of atoms and molecules. The recent measurements of wave-lengths by Rubens and Hollnagel for NaCl, KCl, KBr, and KI down to the seventh octave below the visible spectrum (Phil. Mag. [6] xix. May 1910, p. 761) invite the following brief theoretical investigation.

Suppose an atom to be replaced by the least cube of the same mass and of uniform density that could circumscribe it. Let \( N \) be the rigidity of the material of this cube, \( \rho \) its density, \( m \) its mass, \( m/h = M \) its ordinary atomic weight or mass, and \( R \) the length of the edge of the cube, being equal to the atomic diameter. Here \( h \) is the mass of an atom of hydrogen, \( 1617 \times 10^{-27} \) gramme. The velocity of propagation of a shear or simple distortion without change of volume through the cube is \((N/\rho)^{1/2}\). The simplest type of vibration of the cube would have two opposite faces as middles of internodes so that within the atom the fundamental wave-length = 2R and outside the atom it is \( \lambda = c\tau \), where \( c \) is the

* Communicated by the Author.

velocity of light through vacuum, or through air nearly, and \( \tau \) is the period of vibration of the cube. But \( \tau = 2R/(N/\rho) \), so that \( \lambda = 2cR/(N/\rho) \).

It is convenient for the mathematical analysis to bring in the electric properties of the atom, though we shall not finally use them, as will appear immediately. Let the electric moment of the atom be denoted by \( es \) to be taken as a single symbol, and let \( K \) be its dielectric capacity. Then in "The Electric Origin of Rigidity and Consequences" (Phil. Mag. [6] vii. 1904, p. 417) it is shown that \( N = 2\pi e^2s^3/3KR^6 \), \( K \) being introduced to preserve generality. But in "The Nature of Dielectric Capacity" (Phil. Mag. [6] xix. 1910, p. 1) it was found that as regards the relations of the pairs of electrons forming the atom \( K = 1 \). It has also been found in my papers on the electric origin of cohesion that between atom and atom \( K = 1 \). I have taken this to be evidence that cohesion is due to electric attraction between the electrised molecule and its immediate neighbours, the attraction acting entirely through the \( \alpha \)ether in which \( K = 1 \). Within the atom it appears that the constitutive pairs of electrons act only upon their immediate neighbours through the \( \alpha \)ether with \( K = 1 \). It further appears that when we have taken account of the pairs of electrons forming matter as a cause of dielectric capacity different from 1, we have not to consider any other similar agency in the \( \alpha \)ether. In the formula given above for \( N \) then we put \( K = 1 \). In a recent Phil. Mag. article on Molecular and Electronic Potential Energy I have shown that the cohesive potential energy of unit mass of a substance may be written \( l^2 \) (the \( K\rho^3 \) of Laplace or the \( a/\rho^2 \) of van der Waals) where \( l = 4\pi e^2s^3/m^2 \), the values and laws of \( l \) having been investigated under \( M^2l \) and \( M\rho^4 \) in various papers of mine on molecular attraction. If then in the formula for \( N \) we put \( m^2/4 \) in place of \( e^2s^3 \), we get \( N \) expressed in terms of purely mechanical properties of the atom, the electrical moment \( es \) having been eliminated and \( K \) reduced to 1. Thus for the velocity of propagation of a shear through the atom we obtain the expression \( \lambda l^2/(\pi l^2/6) \), and

\[
\lambda = 2cR/(\pi l^2/6) = 6 \times 10^{10} \times (1617 \times 10^{-27}) \times (M/\rho)^{3/4}/(l^2/\rho)^{3/4} = 973.6 (M/\rho)^{3/4}/(l^2/\rho)^{3/4}.
\]

In the following table are gathered all the requisite data for computing the wave-lengths of the fundamental mechanical vibrations electrically communicated to the \( \alpha \)ether by the atoms of the combined alkali metals and the combined
Mechanical Vibration of Atoms.

halogens, the wave-lengths being given in the last row in terms of \( \mu = 10^{-4} \text{ cm.} \) as unit.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10(^{-6})M(\beta)</td>
<td>2.4</td>
<td>3.5</td>
<td>4.6</td>
<td>6.0</td>
<td>7.3</td>
<td>0.9</td>
<td>2.1</td>
<td>2.7</td>
<td>3.6</td>
</tr>
<tr>
<td>M/(\rho)</td>
<td>2.0</td>
<td>7.4</td>
<td>18.6</td>
<td>34.4</td>
<td>56.0</td>
<td>9.0</td>
<td>19.0</td>
<td>26.0</td>
<td>36.0</td>
</tr>
<tr>
<td>M</td>
<td>7.0</td>
<td>23.0</td>
<td>39.0</td>
<td>85.5</td>
<td>133.0</td>
<td>19.0</td>
<td>35.4</td>
<td>80.0</td>
<td>127.0</td>
</tr>
<tr>
<td>(\rho)</td>
<td>3.50</td>
<td>3.11</td>
<td>2.10</td>
<td>2.485</td>
<td>2.375</td>
<td>2.11</td>
<td>1.86</td>
<td>3.08</td>
<td>3.53</td>
</tr>
<tr>
<td>(\lambda)</td>
<td>19.12</td>
<td>7.069</td>
<td>15.10</td>
<td>28.62</td>
<td>44.03</td>
<td>29.42</td>
<td>35.16</td>
<td>50.59</td>
<td>60.39</td>
</tr>
</tbody>
</table>

To use these results for comparison with the experimental ones of Rubens and Hollnagel, I shall form the wave-length for NaCl by adding those in the table for Na and Cl, thus \( 70.69 + 354.6 = 425.3 \). The next table contains in the first row the wave-lengths thus calculated, in the second the experimental wave-lengths, and in the third the ratio of the calculated to the experimental wave-length.

<table>
<thead>
<tr>
<th></th>
<th>NaCl.</th>
<th>KCl.</th>
<th>KBr.</th>
<th>KI.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\lambda) calcul.</td>
<td>425.3</td>
<td>505.6</td>
<td>636.9</td>
<td>754.9</td>
</tr>
<tr>
<td>(\lambda) exper.</td>
<td>517.4</td>
<td>63.4</td>
<td>82.3</td>
<td>96.4</td>
</tr>
<tr>
<td>Ratio</td>
<td>8.23</td>
<td>7.97</td>
<td>7.98</td>
<td>7.83</td>
</tr>
</tbody>
</table>

The mean value of the ratio is 8.00. It is rather by chance that this ratio comes so exactly to 8, since the separate experimental determinations of these large wave-lengths, and the data and approximations used in the theoretical calculations, do not lead us to expect such exactness at the present. But it is sufficiently remarkable that we have found the calculated mechanical period of vibration and wave-length to be nearly three octaves below the lowest experimental period and length yet measured in each case. The theoretical fundamental wave-length for LiF is 313.3 \(\mu\), which is only between one and two octaves below the longest wave measured by Rubens and Hollnagel for KI.

It is necessary to comment on the process of adding the wave-length for combined Na to that for combined Cl to obtain the wave-length for NaCl. Let us consider an analogous case in acoustics. Suppose a length of tube \( l_1 \) is filled with gas 1, say hydrogen, and with both ends open is caused to sound, its period of vibration \( \tau_1 \) is \( 2l_1/v_1 \), where \( v_1 \) is the velocity of propagation of sound through gas 1. For a length \( l_2 \) filled with gas 2, for instance carbon dioxide, we have \( \tau_2 = 2l_2/v_2 \). If now the two tubes were placed so as to form a single one of length \( l_1 + l_2 \) open at both ends, but the part \( l_1 \) still filled with gas 1 and \( l_2 \) with 2, and the combined

\[ 2 \times 2 \]
system were sounded, would the period of vibration be $\tau_1 + \tau_2$? In the case where the gases 1 and 2 become identical we know that the period of the combined system is obtained correctly by adding together the corresponding values of $\tau_1$ and $\tau_2$. I do not know of the general case with two unlike gases having been tried. In the radiational case of NaCl, KCl, KBr and KI just considered, we have found that the periods of the two atoms in each compound have to be added together to give the period for the molecule. Now an exactly similar result was brought out in my paper on "A New Periodic Property of the Elements" (Phil. Mag. [5] xxx.) with a correction in "A Kinetic Theory of Solids" (ibid. xxxii.), and further consideration in "The Cause of the Structure of Spectra" (ibid. [6] ii.). It was shown that the atoms of the metallic elements and the molecules of their compounds at their melting-points have characteristic oscillations. The period of oscillation for a compound molecule like NaCl is shown to be obtainable as the sum of a period for Na and a period for Cl. This fact supports the assumption made above that in calculating the mechanical period of vibration and wavelength of NaCl we are to add the periods and lengths for Na and Cl. Moreover it is interesting to recall that the kinematical explanation which I have offered for the origin of Balmer's formula leads to the consideration of the period of each spectral line as the sum of two periods. From the calculations given above it appears that ordinary harmonic relations are to be expected amongst the wave-lengths of a substance in the extreme infra-red.

Melbourne, June 1910.

LXXI. Musical Arc Oscillations in Coupled Circuits. By E. Taylor Jones, D.Sc., Professor of Physics in the University College of North Wales, and David E. Roberts, B.Sc., Isaac Roberts Student of the University College of North Wales, Bangor*.

[Plate XIII.]

In a former communication† a number of photographs were reproduced showing the variation of potential at the terminals of the secondary of a pair of coupled circuits when the two oscillations of the system are simultaneously maintained by a musical arc connected to the primary. In

* Communicated by the Authors.
† E. T. Jones and Morris Owen, Phil. Mag. November 1909, p. 713.