



# LIII. On specific heat

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that the laws of propagation just obtained for circular vibrations are equally true for elliptical and rectilineal vibrations; for, as is well known, we may produce elliptically or plane polarized light by superposing two rays of circularly polarized light.

The second consequence is this, that

$$\frac{T}{v} = C_1 - C_3 n^2 + C_5 n^4 \dots \dots \&c.$$

$$\frac{N}{v} = n (C_2 - C_4 n^2 + C_6 n^4 \dots \dots \&c.),$$

where  $C_1 C_2 C_3 \dots \dots \&c.$  are constants independent of  $n$  and of the amplitude of vibration. I shall reserve the proof of this for my next communication, in which I shall also attempt an explanation of the rotation of the plane of polarization produced by certain liquids, the peculiar absorbing power of tourmaline, and some other phænomena.

Balham, Surrey, September 24, 1844.

### LIII. *On Specific Heat.* By J. P. JOULE, Esq.\*

**T**HE well-known law which applies to the specific heat of many simple bodies, while interesting in itself as one of the doctrines of physical science, is of great importance to theoretical chemistry as a criterion for the determination of atomic weights. Dulong and Petit, the philosophers who first announced that the specific heat of simple bodies is inversely proportional to their atomic weights, proved their proposition by experiment in the case of several solid (chiefly metallic) bodies. Subsequently several attempts have been made to discover the law of the specific heat of gases, liquids and compound bodies. With regard to gases, Haycraft†, and subsequently De la Rive and Marcet‡, have attempted to prove that under the same pressure and volume all gases have the same specific heat. Unfortunately, the practical difficulty of ascertaining the specific heat of æriform fluids is so great, that considerable uncertainty exists in the results obtained by the most skilful experimenters, and hence we find that the law of Haycraft, De la Rive and Marcet has failed to be confirmed by the

\* Communicated by the Author, having been read before the Chemical Section of the British Association at York, September 27, 1844.

† Trans. of the Royal Society of Edinburgh, vol. x. part 1. p. 215. (or Phil. Mag. S. 1. vol. lxiv. p. 200.)

‡ *Annales de Chimie*, 1827, tome xxxv. p. 27.

researches of De la Roche and Berard, Dr. Apjohn\*, and Dulong. With compound bodies, however, experimenters have met with better success. Neumann†, in the cases of the carbonates and sulphates of protoxides, has pointed out the fact that the specific heat in each of these classes is inversely proportional to the atomic weight. His researches on some oxides and sulphurets also conducted him to a similar law for each of these species of compounds.

Of late years no philosopher has made more numerous or more accurate experiments on specific heat than Mr. V. Regnault. The investigations of this eminent chemist were, in the first instance, directed to the specific heat of simple solid bodies‡: subsequently they have been directed to a great variety of compound bodies§. By these researches Regnault has given the law of Dulong and Petit all the confirmation that could be desired, and has also proved the correctness of Neumann's extension of that law to classes of chemical compounds. He has stated a general law in the following terms:—"In all compound bodies of the same atomic composition, and of similar chemical constitution, the specific heats are inversely proportional to the atomic weights."

Regnault remarks that the above law holds good only within certain limits, and that the slight differences which are observed between the results of theory and observation are not wholly to be attributed to mere errors of experiment. He says that if the specific heat were taken for the temperature at which the bodies present the greatest analogy in their chemical and physical properties, the most complete isomorphism, the law would probably hold good rigorously.

Now, without denying altogether the influence of a change of state on the specific heat of a body, I think it may be fairly doubted whether it is really so great as is generally imagined. Impressed with this idea, I have been induced to draw up a Table, in which the theoretical specific heats of a variety of bodies impartially selected are calculated on the hypothesis that the capacity for heat of any simple atom remains the same in whatever chemical combination it enters. The law implied by this hypothesis is, that the specific heat of all bodies is directly as the number of atoms in combination, and inversely as the equivalent.

\* Trans. of the Royal Irish Academy, vol. xviii. part 1. p. 16. (or Phil. Mag. S. 3. vol. xii. p. 101.)

† Poggendorff's *Annalen*, vol. xxiii.

‡ *Annales de Chimie*, 1840, vol. lxxv. p. 1.

§ *Ibid.*, 1841, vol. i. p. 129.

Name of substance.	Formula adopted.	No. of atoms divided by equivalent.	Theoretical sp. heat.	Actual sp. heat.	Experimenter.
Water .....	H <sub>2</sub> O	$\frac{8}{8}$	1000	1000	[Berard.
Hydrogen .....	H <sub>2</sub>	$\frac{1}{1}$	6000	3294	De la Roche and
Oxygen .....	O	$\frac{8}{8}$	375	236	do.
Sulphur .....	S	$\frac{16}{16}$	188	188	Dulong and Petit.
Iodine .....	I	$\frac{127}{127}$	48	54	V. Regnault.
Carbon .....	C	$\frac{12}{12}$	250	241	do.
Lead .....	Pb	$\frac{207}{207}$	29	29	Dulong and Petit.
Zinc .....	Zn	$\frac{65}{65}$	91	93	do.
Copper .....	Cu	$\frac{63}{63}$	94	95	do.
Mercury .....	Hg	$\frac{200}{200}$	30	33	do.
Protoxide of lead .....	PbO	$\frac{223}{223}$	54	51	V. Regnault.
Protoxide of copper ...	CuO	$\frac{79}{79}$	150	142	do.
Magnesia .....	MgO	$\frac{40}{40}$	286	244	do.
Peroxide of iron .....	Fe <sub>2</sub> O <sub>3</sub>	$\frac{160}{160}$	192	167	do.
Subsulphuret of copper	Cu <sub>2</sub> S	$\frac{159}{159}$	113	121	do.
Protosulphuret of lead	PbS	$\frac{239}{239}$	50	50	do.
Protosulphuret of iron	FeS	$\frac{88}{88}$	140	136	do.
Bisulphuret of iron ...	FeS <sub>2</sub>	$\frac{176}{176}$	153	130	do.
Chloride of sodium ...	Na <sub>2</sub> Cl <sub>2</sub>	$\frac{117}{117}$	207	214	do.
Protochlor. of copper .	Cu <sub>2</sub> Cl <sub>2</sub>	$\frac{135}{135}$	120	138	do.
Chloride of lead .....	PbCl <sub>2</sub>	$\frac{278}{278}$	65	66	do.
Iodide of silver .....	Ag <sub>2</sub> I <sub>2</sub>	$\frac{382}{382}$	51	62	do.
Iodide of lead .....	PbI <sub>2</sub>	$\frac{360}{360}$	39	43	do.
Sulph. acid, sp. gr. 1.85	SO <sub>3</sub> H <sub>2</sub> O	$\frac{81}{81}$	429	350	Dalton.
Carbonate of potash...	2KO+CO <sub>2</sub>	$\frac{138}{138}$	194	216	V. Regnault.
Carbonate of lead.....	2PbO+CO <sub>2</sub>	$\frac{325}{325}$	101	86	do.
Sulphate of lead .....	PbOSO <sub>3</sub>	$\frac{286}{286}$	118	87	do.
Sulphate of potash ...	KOSO <sub>3</sub>	$\frac{174}{174}$	204	190	do.
Chlorate of potash ...	KOCl <sub>2</sub> O <sub>5</sub>	$\frac{190}{190}$	220	210	do.
Nitrate of potash .....	KON <sub>2</sub> O <sub>5</sub>	$\frac{108}{108}$	265	238	do.
Alcohol .....	C <sub>2</sub> H <sub>10</sub> O+H <sub>2</sub> O	$\frac{46}{46}$	1043	622	Despretz.

The substances chosen in the construction of the above Table are, as I have said, impartially selected. I have omitted some in which the theory was found to agree perfectly with experiment, whilst I have inserted others (as, for instance, alcohol) which appear to disagree with the theory very considerably. On the whole the coincidence between the theoretical and experimental results is such that I think chemists will agree with me in believing that the law of Dulong and

Petit, with regard to simple atoms, is capable of a greater degree of generalization than we have hitherto been inclined to admit.

LIV. *Demonstration of the proposition that every function  $F(\mu, \omega)$  which does not become infinite between the limiting values  $-1$  and  $1$  of  $\mu$  and  $0$  and  $2\pi$  of  $\omega$  may be expanded in a series of Laplace's Coefficients.*

To the Editors of the Philosophical Magazine and Journal.

GENTLEMEN,

YOU will not perhaps think the following concise demonstration of this most important proposition unworthy of your consideration, based though it be on demonstrations already before the public. I am, your obedient Servant,

PROCU.

Let  $\mu \mu' + \sqrt{1-\mu'^2} \sqrt{1-\mu^2} \cos(\omega' - \omega) = p$ ;  
and suppose that

$$(1+c^2-2cp)^{-\frac{1}{2}} = P_0 + P_1c + P_2c^2 + \dots + P_ic^i + \dots$$

then it is known\* that  $P_0, P_1, \dots$  are some of Laplace's coefficients. Differentiate with respect to  $c$ , multiply by  $2c$ , and add the result to the above, and we have

$$\frac{1-c^2}{(1+c^2-2cp)^{\frac{3}{2}}} = P_0 + 3P_1c + \dots + (2i+1)P_ic^{i-1} + \dots$$

When  $c = 1$  this series equals *zero*, except when  $p = 1$ , in which case it appears to be indeterminate; but it is easy to show that in that case it equals *infinity*, for each of the coefficients  $P_0, P_1, \dots$  becomes *unity* when  $p = 1$ †. It is not difficult‡, moreover, to show that when  $p = 1, \omega = \omega'$  and  $\mu = \mu'$ . Hence we arrive at this remarkable result, that the series

$$P_0 + 3P_1 + 5P_2 + \dots + (2i+1)P_i + \dots$$

equals *zero* for all values of the variables, except when  $\mu = \mu'$  and  $\omega = \omega'$ , in which particular case it equals *infinity*. The series is therefore *discontinuous*, and will destroy any finite function by which it is multiplied, except for those particular values of the variables; it will destroy the multiplying function even for values of the variables differing by the smallest infinitesimal quantities from those which satisfy the conditions  $\mu = \mu'$  and  $\omega = \omega'$ ; this is because the value of the series is discontinuous, and *per saltum* passes from zero to infinity. Having premised thus far, if we integrate the series as it stands, term after term, then by the known§ property of Laplace's co-

\* Pratt's Mechanical Philosophy, Second Edition, p. 161.

† Ibid. p. 160.

‡ Ibid. p. 166.

§ Ibid. p. 165.