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LXXVIII.—*On the Heat of Vapours and on Astronomical Refractions. By* JOHN WILLIAM LUBBOCK, *Esq., Treas. R.S. F.R.A.S. and F.L.S., Vice-Chancellor of the University of London, &c.*

[Continued from p. 441.]

ON THE PRESSURE OF STEAM.

THE most accurate and extensive experiments by which the accuracy of these relations can be tested are those which have been made upon the conditions of steam. The following are the experiments of Arago and Dulong, as recorded in tom. x. of the *Mémoires de l'Institut*, p. 231; together with the temperatures calculated by the best empirical formulæ*.

Nos. des observations.	Elasticité en mètres de mercure à 0°.	Elasticité en atmosph. de 0m·76.	Température observée.	Température calculée par la formule de Tredgold.	Température calculée par la formule de Roche cöeff. moyen.	Température calculée par la formule de Coriolis.	Température calculée par la formule adoptée.
			Cent.	Cent.	Cent.	Cent.	Cent.
1	1·62916	2·14	123°·7	123°·54	123°·58	123°·45	122°·97
3	2·1816	2·8705	133·3	133·54	133·43	133·34	132·9
5	3·4759	4·5735	149·7	150·39	150·23	150·3	149·77
8	4·9383	6·4977	163·4	164·06	163·9	164·1	163·47
9	5·6054	7·3755	168·5	169·07	169·09	169·3	168·7
15	8·840	11·632	188·5	188·44	188·63	189·02	188·6
21	13·061	17·185	206·8	206·15	207·04	207·43	207·2
22	13·137	17·285	207·4	206·3	206·94	207·68	207·5
25	14·0634	18·504	210·5	209·55	210·3	211·06	210·8
28	16·3816	21·555	218·4	216·29	218·01	218·66	218·5
30	18·1894	23·934	224·15	222·09	233·4	224·0	224·02

There are reasons which make it probable that in inquiries of this nature the scale of temperature as indicated by the expansion of air is to be preferred, although the difference between the indications of a mercury thermometer with that of air is not considerable.

The following table is given by M. Pouillet (*Elémens de Physique*, vol. i. p. 259) for the centigrade scale:

Températures indiquées par le therm. à mercure, à enveloppe de verre.	Températures indiquées par un therm. à air, et corrigées de la dilatation du verre.	Volumes corrèspondans d'une même masse d'air.
− 36°	− 36°	0·8650
0	0	1·0000
100	100	1·3750
150	148·70	1·5576
200	197·05	1·7389
250	245·05	1·9189
300	292·70	2·0976
Ebull. du merc. 360	350·00	2·3125

[* Many of the results stated in the table of the French chemists are absolutely identical with those which had been published by Mr. Philip Taylor in 1822. See his Paper in the Philosophical Magazine, First Series, vol. lx. p. 452., and the accompanying engraved Table of his experimental results.—EDIT.]

From the above I have deduced the following Table for Fahrenheit's scale:

Merc. therm.	Air therm.	Merc. therm.	Air therm.
212°	212°	482°	478°·1
302	299·7	572	558·9
392	386·7	680	662·0

I now proceed to determine for steam the constants γ and E by means of the observations of Dulong and Arago which I have quoted in the preceding page.

For the air thermometer on Fahrenheit's scale the experiments of Dulong and Arago (*Mém. de l'Institut*, vol. x.) give, θ being reckoned in Fahrenheit's scale and from the freezing point of water,

$$p = 1 \qquad \theta = 180 \qquad \frac{1}{\alpha} = 480^\circ$$

$$p' = 11{\cdot}632 \qquad \theta' = 334{\cdot}7 \qquad \frac{1}{\alpha} + \theta' = 814{\cdot}7$$

$$p'' = 23{\cdot}934 \qquad \theta'' = 396{\cdot}4 \qquad \frac{1}{\alpha} + \theta'' = 876{\cdot}4.$$

I find from these observations

$$\frac{p''^{\beta} - 1}{p'^{\beta} - 1} = [0{\cdot}1140623],$$

the quantity within brackets being the logarithm of the corresponding number; and hence I find

$$\beta = {\cdot}0134^* \qquad \gamma = {\cdot}98677 \qquad \frac{1}{\gamma} = 1{\cdot}0134$$

$$E = 1{\cdot}17602 \qquad \log E = {\cdot}0704184 \qquad H = 6{\cdot}6809.$$

The pressure at the boiling point of water (212°) being unity,

$$\frac{1}{\alpha} + \theta = -\frac{[2{\cdot}0651059]}{p^{{\cdot}0134} - 1{\cdot}17602};$$

so that if τ is the number of degrees on Fahrenheit's scale of the air thermometer, and the pressure p be reckoned in atmospheres,

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* This value of β appears to me to be the only one which will satisfy the equation.

$$\tau = -\frac{[2{\cdot}0651059]}{p^{{\cdot}0134} - 1{\cdot}17602} - 448^{\circ},$$

and if ϱ be the density of steam, the relative volume

$$\frac{\varrho}{\varrho'} = \frac{p\,\{p^{{\cdot}0134} - 1{\cdot}17602\}}{p'\,\{p'^{{\cdot}0134} - 1{\cdot}17602\}}.$$

In order to ascertain how far the new expression here given for τ represents the totality of the observations, I have calculated the temperatures corresponding to all the observed pressures in the observations of Arago and Dulong, and the results are exhibited in the following table.

Pressure in atmospheres.	Temperature.				Error of temperature calculated by Lubbock. Fahr.
	Observed.			Calculated.	
	Merc. therm. Cent.	Merc. therm. Fahr.	Air therm. Fahr.	Air therm. Fahr.	
2·1400	123°·7	254°·66	253°·6	252°·8	–°·8
2·8705	133·3	271·94	270·4	270·1	–·3
4·5735	149·7	301·46	299·2	299·4	+·2
6·4977	163·4	326·12	323·0	323·2	+·2
7·3755	168·5	335·30	331·9	332·3	+·4
11·6320	188·5	371·30	366·7*	366·7	0
17·1850	206·8	404·24	398·6	398·9	+·3
17·2850	207·4	405·32	399·5	399·4	–·1
18·5040	210·5	410·90	404·9	405·3	+·4
21·5550	218·4	425·12	418·5	418·8	+·3
23·9340	224·15	435·47	428·4*	428·5	+·1

The observations marked with an asterisk were employed in determining the constants.

The error of the temperature calculated by the formula adopted by Arago and Dulong corresponding to the first observation is – ·73 cent. or –1°·3 of Fahr. I have no doubt that the observed temperature is in excess, and the agreement with the rest of the observations is so complete, that within this range of temperature the formula may, I think, be considered as exactly representing the phenomena. The errors of the temperatures, calculated by the various empirical expressions which have been hitherto proposed, are much greater, as may be seen in the table of Dulong and Arago. The following observations are those of Southern, given in p. 172, vol. ii., of Dr. Robison's Mechanical Philosophy.

Pressure.	Temperature.		Error of calculated temp.	Pressure.	Temperature.		Error of calculated temp.
	Observed.	Calculated.			Observed.	Calculated.	
Inch.		°	°	Inch.			°
·52	62	59·5	−2·5	4·68	132	131·4	−·6
·73	72	69·3	−2·7	6·06	142	141·3	−·7
1·02	82	79·3	−2·7	7·85	152	151·6	−·4
1·42	92	89·9	−2·1	9·99	162	161·7	−·3
1·95	102	100·2	−1·8	12·64	172	171·8	−·2
2·65	112	110·7	−1·3	15·91	182	182·0	0
3·57	122	121·3	− ·7	29·80	212	212·	

The formula deviates slightly from the observations at very low pressures. Dalton says that it is next to impossible to free any liquid entirely from air; of course if any air enter, it unites its force to that of the vapour.—*Manchester Memoirs*, vol. v. p. 570. It must be recollected that according to theory the constants γ and E are the same only as long as the chemical constitution of the vapour remains the same, and they vary for different substances.

With regard to the nature of the accurate expression which connects the pressure with the temperature, opinions have hitherto been various. According to Dr. Robison, Mr. Watt found that water would distil *in vacuo* when of the temperature of 70°, and that in this case the latent heat of the steam appeared to be about 100°; and some other experiments made him suppose that the sum of the sensible and latent heats is a constant quantity. This, Dr. Robison says, is a curious and not improbable circumstance. Southern, on the contrary, concluded from experiments on the latent heat of steam at high temperatures that the *latent heat* is a constant quantity, instead of the latent heat + sensible heat being so. M. de Pambour, in speaking of Southern's view, says, "Cette opinion a paru plus rationelle à quelques auteurs, mais le première nous semble mise hors de doute par les observations que nous allons rapporter." It appears to me by no means clear that Watt entertained the opinion here attributed to him, for in a note in the Appendix to Sir David Brewster's edition of Robison's Mechanical Philosophy, vol. ii. p. 167, he professes to agree in the opinion there delivered by Southern. In p. 166 Southern records three experiments, from which he obtained 1171°, 1212°, and 1245°, for the sums of the latent + sensible heat corresponding to the temperatures or sensible heat 229°, 270°, 295°. If we take the two extreme observations, we find a difference in the sum of the latent + sensible heat of 74 degrees, corresponding to a difference in the sensible heat of 66 degrees.

If the conditions under which Laplace obtained the equation

$$V = A + B\frac{p}{\varrho}^{\frac{1}{\gamma}}$$

are admitted, the value of E different from zero shows that the absolute heat is not constant; but the preceding theory does not appear to me to furnish the means of determining the value of D, and hence of deciding with certainty whether the latent heat is constant, and whether in augmentations of heat the sensible heat only varies. I think there can be little doubt that the conditions assumed by Laplace actually obtain, and that the hypothesis attributed to Watt* must be abandoned. The experiments recorded by Mr. Parkes in the 3rd volume of the Transactions of the Society of Civil Engineers, p. 71, which show that the quantity of fuel required to evaporate a given weight of water is nearly the same whatever be the pressure of the steam, do not seem to me to authorize a different conclusion. For this is precisely what would take place if the *latent* heat be constant, and if the quantity of fuel required to generate the *latent* greatly exceed that required to generate the concomitant *sensible* heat.

The quantity γ has never before been determined for steam† or for the vapour of any liquid, properly so called, as far as I am aware. It may excite surprise that the value of γ should come out less than unity. Both Poisson and Dulong assert that it is evident that γ must surpass unity, but the reason which they assign appears to me inconclusive.

[To be continued.]

LXXIX. *On the Combinations of Carbon with Silicon and Iron, and other Metals, forming the different Species of Cast Iron, Steel, and Malleable Iron. By* Dr. C. Schafhaeutl, *of Munich.*

[Continued from p. 434.]

THE brown residuums of all white irons, when boiled with hydrochloric acid before ignition, parted with their iron with extreme difficulty. In one trial after boiling the mixture in a bottle whose neck was shut up with a capillary tube; first no apparent change took place, and only hydrochloric acid escaped; after boiling an hour the contents of the bottle began to become thickish, a disagreeably smelling gas escaped, which when ignited burned with a small but intensely blue-coloured flame.

* Mr. Sharpe has maintained the same opinion in the 2nd vol. of the Manchester Memoirs. See Dr. Thomson's Outline of Heat and Elasticity, p. 198.

† "Quant à la valeur de γ, elle nous est jusqu'à present tout-à-fait inconnue."—Poisson, *Méc.*, tom. ii. p. 652.