

at the joints where the ties and braces are connected with the chords ; and the same effect would be produced upon the trussing if the load were divided into as many equal weights as there are bays, and each weight were supported directly by the ties and braces. This hypothesis will enable us to slightly modify the preceding equations. They may also be modified for many forms of trusses so as to be more convenient for computation. These modifications will form the subject of the next article.

(To be Continued.)

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## MECHANICS, PHYSICS, AND CHEMISTRY.

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### *Note on the Variations of Density produced by Heat in Mineral Substances.* By Dr. T. L. PHIPSON, F.C.S.

From the London Chemical News, No. 235.

That any mineral substance, whether crystallized or not, should diminish in density by the action of heat, might be looked upon as a natural consequence of dilation being produced in every case and becoming permanent. Such diminution of density occurs with idocrase, Labradorite, feldspar, quartz, amphibole, pyroxene, peridot, Samarskite, porcelain, and glass. But Gadolinite, zircons, and yellow obsidians augment in density from the same cause. This again may be explained by assuming that, under the influence of a powerful heat, these substances undergo some permanent molecular change. But in this note I have to show that this molecular change is not permanent, but intermittent, at least as regards the species I have examined, and probably with all the others. Such researches, while tending to elucidate certain points of chemical geology, may likewise add something to our present knowledge of the modes of action of heat. My experiments were undertaken to prove an interesting fact announced formerly by Magnus—namely, that specimens of idocrase after fusion had diminished considerably in density without undergoing any change of composition: before fusion their specific gravity ranged from 3·349 to 3·45, and after fusion only 2·93 to 2·945. Having lately received specimens of this and other minerals brought from Vesuvius in January last by my friend Henry Rutter, Esq., I determined upon repeating this experiment of Magnus. I found, first, that what he stated for idocrase and for a specimen of reddish-brown garnet was also the case with the whole family of garnets as well as for the minerals of the idocrase groupe; secondly, that it is not necessary to melt the minerals: it is sufficient that they should be heated to redness without fusion, in order to occasion this change of density; thirdly, that the diminished density thus produced by the action of a red heat is not a permanent state, but that the specimens, in the course of a month or less, resume their original specific gravities. These curious results were first obtained by me with a species of lime garnet in small yellowish crystals, exceedingly brilliant and resinous, almost granular, fusing with difficulty to black enamel, accompanied with very little

leucite and traces of grossular, and crystallized in the second system. Specimens weighing some grammes had their specific gravity taken with great care, and by the method described by me in the *Chemical News* for 1862. They were then perfectly dried and exposed for about a quarter of an hour to a bright red heat. When the whole substance of the specimen was observed to have attained this temperature, without a trace of fusion, it was allowed to cool, and when it had arrived at the temperature of the atmosphere, its specific gravity was again taken by the same method as before. The diminution of density being noted, the specimens were carefully dried, enveloped in several folds of filtering paper, and put aside in a box along with other minerals. In the course of a month it occurred to me that it would be interesting to take the specific gravity again, in order to ascertain whether it had not returned to its original figure, when, to my surprise, I found that each specimen had effectively increased in density and had attained its former specific gravity. Thus:

*Lime garnet mellitite (from Vesuvius).*

Original Density.	Density after being heated red-hot for a quarter of an hour and allowed to cool.			Density determined in a month after the experiments.
I. 3.345	.	.	2.978	3.344.
II. 3.350	.	.	2.980	3.350.
III. 3.349	.	.	2.977	3.345.

The same experiments were made with several other minerals belonging to the idocrase and garnet family, and always with similar results. Now I ask, what becomes of the heat that seems to be thus shut up in a mineral substance for the space of a month? The substance of the mineral is dilated, the distance between its molecules is enlarged, but these molecules slowly approach each other again, and in the course of some weeks resume their original positions. What induces the change, or how does it happen that the original specific gravity is not acquired immediately the substance has cooled? Will the same phenomenon show itself with other families of minerals or with the metallic elements? Such are the points which I propose to examine in the next place; in the mean time the observations I have just alluded to are proof that bodies can absorb a certain amount of heat not indicated by the thermometer (which becomes latent), and that this is effected without the body undergoing a change of state; secondly, that they slowly part with this heat again until they have acquired their original densities; thirdly, so many different substances being affected by a change of density when melted or simply heated to redness and allowed to cool, it is probable this property will be found to belong, more or less, to all substances without exception.

\* Some minerals, like euclase, that become electric by heat, retain that state for a considerable time. The increase of density of Gadolinite and the decrease of density of Samarskite by action of heat, are accompanied by a vivid emission of light, as mentioned in my work on "Phosphorescence," &c., pp. 31 and 32, where H. Rose's ingenious experiment is described.

*On the Pressure of Steam at high Temperatures.* By R. A. PEACOCK, C.E.

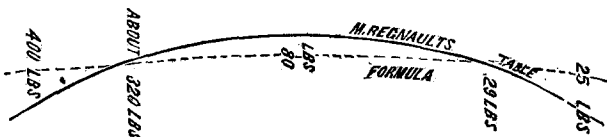
From the London Artizan, Feb., 1864.

(Continued from page 124.)

The reader has now the means of forming his own opinion as to the degree of reliance which can be placed on the formula. That is to say, if he accepts Dr. Fairbairn's temperature with the respective pressures of 56·7 and 60·6 lbs, and discards M. Regnault's temperatures, which are about  $\frac{2}{3}$  of a degree Fahr. greater for equal pressures, then the formula will be as accurate as could be expected or even wished for. Because we should have as follows:—

Pressure.		Temperature. Fahrenheit.	Formula.	Differences.
lbs. per sq. in.				
30	M. Regnault	250·23	250·17	+·06
56·7	Dr. Fairbairn	288·25	288·20	+·05
60·6	Ditto	292·53	292·48	+·05
300	M. Regnault	417·50	417·32	+·18
336·3	Dr. M. Rankine*	428·00	428·05	—·05

These differences are exceedingly small. But if on the other hand, any reader rejects Dr. Fairbairn's experiments aforesaid and adopts M. Regnault's table throughout, the formula will be valueless to him for pressures greater than about 400 lbs to the square inch. Because M. Regnault's table gives a temperature less than the formula by ·24 for 25 lbs, this difference gradually diminishes with increasing pressures until at 29 lbs the table and the formula are exactly equal. With higher pressures the table gives temperatures in excess of the formula, which excess gradually increases until it attains its maximum of ·73° Fahr. at 80 lbs, after which the excess gradually diminishes, until the table and formula would be identical at about 320 lbs pressure. After which the formula would be in excess of the table, which excess would be greater and greater, until, as aforesaid, at about 400 lbs. pressure, the formula would cease to be of any value to the reader in question. These variances will be more readily apprehended by considering the following diagram, where the full line represents the temperatures in M. Regnault's table, and the dotted the temperatures of the formula:—



\* This is supposing Dr. M. Rankine's to be an experiment and not a calculation.

By which it will be seen that the formula, after about 400 lbs, will necessarily diverge more and more from the table. The diagram shows the *manner* of the discrepancy, greatly exaggerated in *degree*.

The formula is as follows:—It has been stated that the temperature increases as the  $4\frac{1}{2}$  root of the pressure in lbs per square inch. Now for a pressure of 29 lbs. to the square inch both M. Regnault's table and formula give the same temperature, viz:  $248\cdot3^{\circ}$ , let it therefore be assumed accordingly as a basis to commence from. We shall then have by the formula, supposing the temperature to give a pressure of 300 lbs. is required—

$$\frac{\log. \text{ of } 29 \text{ lbs.}}{4\cdot5} : \log. \text{ of } 248\cdot3^{\circ} :: \frac{\log. \text{ of } 300 \text{ lbs.}}{4\cdot5} : \log. \text{ of } 417\cdot32^{\circ}$$

which is the temperature required, as per table appended hereto. But this process may be shortened. The following is the working formula and gives the same results with half the labor, which is of importance where the calculations are numerous. By it the following table was calculated. No basis is required, the temperature is ascertained at once by adding the constant log.  $2\cdot07$ , which is equivalent to adding the second term and deducting the first.

*Working formulas.*—When the temperature to produce a given pressure is required:—

*Rule.*—Divide the log. of the given pressure by  $4\cdot5$ , and add log.  $2\cdot07$ ; the sum is the log. of the temperature required.

*Example.*—Required, the temperature to produce a pressure of 29 lbs per square inch?

$$\frac{\log. \text{ of } 29 \text{ lbs.}}{4\cdot5} + 2\cdot07 = \log. \text{ of } 248\cdot3^{\circ} \text{ the temperature required.}$$

Or when the pressure produced by a given temperature is required, we have only to reverse the operation. Thus, let it be required what pressure per square inch will a temperature of  $417\cdot32^{\circ}$  Fahr. produce? Here we have

$$\log. \text{ of } 417\cdot32^{\circ} - \log. 2\cdot07 \times 4\cdot5 = \log. \text{ of } 299\cdot93 \text{ lbs.}^*$$

the pressure required.

Or, again, let it be required what will be the pressure of steam of a temperature of  $3000^{\circ}$  Fahr. which Sir W. G. Armstrong assumed as the temperature of subterranean fusion in his address to the British Association.

$$\log. \text{ of } 3000^{\circ} = 3\cdot4771213 - 2\cdot07 = 1\cdot4071213 \times 4\frac{1}{2} = 6\cdot3320458 = 2,148,050 \text{ lbs.} = 959 \text{ tons per square inch,}$$

if the formula can be depended on so far, and it would be difficult to prove either an affirmative or a negative, if we adopt Dr. Fairbairn's experiments.

It thus appears that by first ascertaining the temperature of saturated steam in a boiler, we at once get the pressure. Professor Daniell, F.R.S., ascertained the heat of a common fire to be  $1141^{\circ}$

\* The correct temperature by the rule for 300 lbs. is not  $417\cdot32^{\circ}$ , but  $417\cdot322 + ^{\circ}$ .

Fahr. ; this would give by the formula a pressure of upwards of 12 tons per square inch. Now, supposing an ordinary boiler, made of  $\frac{3}{4}$  boiler plate ; of course the strength of the plates would be reduced in strength at the joints by the rivet holes, and additionally by the length of the boiler, if that was considerable—short boilers being much stronger than long ones—a plate here and there would also be sure to be defective. All this being considered, there is no reason for surprise that such boilers should burst where the pressure may be of any amount up to, and even exceeding, 12 tons per square inch. At the same time, it is probably quite true that explosions sometimes take place from other causes than excessive pressure of steam directly on boiler plates.

Dr. Fairbairn's experiments on the tensile strength of rivet iron prove that iron may be heated up to about 400° Fahr. without impairing its strength.\* This temperature gives a pressure of 250 lbs. per square inch. Now, if steam can be conveniently and economically heated up to this point (which ought not to be exceeded), it follows that boilers might be made much smaller than they are at present, where the pressure often does not exceed one-tenth part of 250 lbs. In that case, of course, the boilers must be made much stronger ; they might, in fact, be made of thin armor plates of Bessemer's steel, joined together with double rows of rivets first, and then be properly bound together with steel bars.

To ascertain the steam pressure correctly, the following plan might be adopted. Provide a coiled steel spring suitably strong, carrying an index, and contained in a case or cavity like an ordinary letter weigher. Place actual weights of different amounts on the top of the brass piston, and graduate accordingly. This will prevent mistakes about the actuality of the pressure indicated. Insert the top of this piston of one inch square, on which the steam is to act, through the top plate of the boiler, and fix the instrument firmly there in an inverted position, the index and spring being outside the boiler. The piston may work through a stuffing box. In like manner a thermometer may be affixed, the bulb being inside the boiler. Thus the pressure and temperature can both be read off. The pressure, as has been said, must not be allowed to get above the 250 lbs., so that the boiler would be quite safe from bursting. This plan would apparently settle the question of boiler explosions ; and, the boiler being small, it would not be out-of-the-way expensive, notwithstanding its being made of steel and unprecedentedly strong. In this case the specific volume of the steam, or the ratio of the volume of the steam to that of the water which produced it, would be, according to Dr. Fairbairn's formula, 123.76.

For the purpose of exhibiting in the following table that the temperature gradually increases with the pressure, which ought clearly to be the case if the calculations are correct, the whole of the calculations are given. This will also enable any one to make a comparison between the best known experiments and the calculations.

\* "Useful Information for Engineers," second series, p. 124.

TABLE of Pressures and corresponding Temperatures of Saturated Steam, calculated on the theory that the temperature increases as the  $4\frac{1}{2}$  root of the pressure, and conversely that the pressure increases as the  $4\frac{1}{2}$  power of the temperature.

Pressure.	Calculation.	Pressure.	Calculation.	Pressure.	Calculation.
lbs. per sq. in.	Temp. Fahr. deg.	lbs. per sq. in.	Temp. Fahr. deg.	lbs. per sq. in.	Temp. Fahr. deg.
25	240.24	53	283.90	145.8	355.50
26	242.34	54	285.08	147	356.14
26.5	243.37	55	286.25	150	357.75
27	244.39	55.9	287.28	154.3	360 (1)
27.4	245.19	56	287.40	160	362.91
27.6	245.59	56.7	288.20	163.3	364.56
28	246.37	57	288.53	165	365.40
28.83	247.98	58	289.65	170	367.84
29	248.30	58.8	290.53	170.99	368.31
29.4	249.05	59	290.75	180	372.54
30	250.17	60	291.84	182.4	373.63
31	252.01	60.4	292.27	190	377.04
31.458	252.83	60.6	292.48	195	379.22
32	253.81	65	297.08	200	381.37
33	255.53	66.15	298.23	203.3	382.75
33.1	255.71	67.23	299.31	210	385.52
33.71	256.74	69.21	301.25	220	389.52
34	257.23	70	302.01	225	391.48
35	258.90	73.5	305.30	225.9	391.82
36	260.52	75	306.67	230	393.39
36.75	261.70	79.03	310.26	240	397.13
37	262.11	80	311.10	250	400.75
37.8	263.36	80.85	311.83	252.619	401.68
38	263.67	85	315.32	254.089	402.20
39	265.57	88.2	317.92	255	402.52
39.25	265.57	89.86	319.24	260	404.26
40	266.70	90	319.35	270	407.67
40.3	267.14	95	323.22	272.008	408.33
41	268.16	95.516	323.61	280	410.97
41.7	269.17	95.55	323.63	285	412.60
42	269.60	100	326.92	290	414.19
42.196	269.88	101.9	328.28	300	417.32
43	271.02	102.9	329.01	315	421.87
44	272.40	105	330.49	316.858	422.42
44.1	272.54	108.4198	332.84	330	426.25
45	273.77	110	333.92	336.3	428.05
45.49	274.43	110.25	334.08	345	430.48
45.7	274.70	115	337.24	351.8298	432.36
46	275.11	115.1	337.30	360	434.58
47	276.42	120	340.44	375	438.54
48	277.72	124.95	343.51	400	444.87
49	279.	125	343.54	420	449.72
49.4	279.50	129.8	346.43	440	454.40
50	280.25	130	346.55	450	456.67
51	281.49	132.3	347.90	460	458.91
51.45	282.02	135	349.47	480	463.27
51.7	282.34	139.65	352.11	500	467.49
52	282.70	140	352.30	520	471.58 (2)
52.52	283.33	145	355.06	540	475.55

<sup>1</sup> Soft solder, two parts tin and one part lead, melts at 360°.

<sup>2</sup> Bismuth melts, 471.6°. (Dixon on heat.)

Pressure.	Calculation.	Pressure.	Calculation.	Pressure.	Calculation.
lbs. pr sq.in.	Temp. Fahr. deg.	lbs. pr sq.in.	Temp. Fahr. deg.	pr sq.in. Tons. lbs.	Temp. Fahr. deg.
550	477-49	1900	628-94	8½	1049-63
560, ¼ ton	479-41	1984	635 (2)	8¾	1056-41
580	483-16	2000	636-15	9	1063-05
600	486-82	2055	640 (3)	9¼	1069-54
620	490-38	2100	643-09	9½	1075-90
635	492-99	2200	649-77	9¾	1082-13
650	495-56	2240, a ton	652-37	10	1088-23
660	497-24	Tons. lbs.		10½	1094-22
680	500-55	1 152	662 (4)	10¾	1100-10
700	503-78	1½	685-54	10¾	1105-86
720	506-95	1¾	713-89	11	1111-53
740	510-04	1¾	738-77	11½	1117-09
750	511-57	2	761-02	11½	1122-56
760	513-08	2¼	781-20	11¾	1127-94
780	516-04	2½	799-71	12	1133-23
800	518-96	2½ 73	802 (5)	12¼	1138-43
820	521-81	2¾ 332	810 (6)	12 839	1141 (s)
840	524-61	2¾	816-82	12½	1143-50
850	526	3	832-77	12¾	1148-60
860	527-36	3¼	847-72	13	1153-66
880	530-06	3½	861-80	13½	1158-46
900	532-71	3¾	875-11	13½	1163-28
920	535-33	4	887-75	13¾	1168-03
940	537-89	4¼	899-79	14	1172-72
950	539-16	4½	925-37	14½	1177-34
960	540-41	4¾	932-30	14¾	1181-90
980	542-90	5	932-88	14¾	1186-40
1000	545-34	5½	943-05	15	1190-84
1050	551-28	5¾	952-85	15½	1195-22
1100	557-01	5¾	962-31	15¾	1199-54
1120, ½ ton	559-25	6	971-45	15¾	1203-82
1200	567-89	6½	980-30 (7)	16	1208-04
1279-09	576- (1)	6½	988-88	17	1224-42
1300	578-08	6¾	997-21	18	1240-07
1400	587-68	7	1005-31	19	1255-06
1500	596-76	7¼	1013-17	20	1269-45
1600	605-38	7½	1020-84	25	1334
1680, ¾ ton	611-98	7¾	1028-30	30	1389-15
1700	613-59	8	1035-58	50	1556-14
1800	621-43	8½	1042-69	100	1815-28

<sup>1</sup> Lead melts, 576°.

<sup>2</sup> Iron, red heat in the dark, 635°.

<sup>3</sup> Linseed oil boils, 640°.

<sup>4</sup> Mercury boils, 662°.

<sup>5</sup> Charcoal burns, 802°.

<sup>6</sup> Antimony melts, 810°.

<sup>7</sup> Iron, dull red heat, 980°.

<sup>8</sup> Heat of a common fire, 1141°.

The following are the several melting heats of some of the more refractory metals, with the pressures of steam of equal temperatures calculated by the formula:—

Calculations of Pressure in  
Tons per square inch.

114	.	Brass melts at	.	1869° <sup>11</sup> Fahr.
115	.	Silver "	.	1873° <sup>12</sup> "
153	.	Copper "	.	1996° <sup>13</sup> "
237	.	Gold "	.	2200° <sup>14</sup> "
326	.	.	.	2360° <sup>15</sup> "
687	.	Cast iron "	.	2786° <sup>16</sup> "
959	.	Subterranean fusion	.	3000° <sup>17</sup> "

The temperatures marked <sup>5</sup>, <sup>7</sup>, <sup>8</sup>, <sup>9</sup>, <sup>10</sup>, <sup>11</sup>, <sup>12</sup>, <sup>13</sup>, <sup>15</sup>, are on the authority of Professor Daniell, F.R.S. <sup>15</sup>, the temperature 2360°, is stated by Dr. Macquorn Rankine, F.R.S., to be that about at which the water in an engine boiler would be totally evaporated. (*Artizan* Nov., 1863, p. 252.) <sup>17</sup> In Sir W. G. Armstrong's address to the British Association, at Newcastle (p. 9), he assumes the temperature of the subterranean fusion to be 3000° Fahr. The other melting points, &c., have been obtained from a small volume on steam, published by the late Mr. Weale.

*Earthquakes, Volcanic Explosions and Upheavals of Strata.*—There is another point of view in which this formula may possibly be not without interest to a class of scientific men, other than engineers. More than a century ago the Rev. John Michell, M.A., “conjectured” that steam might be the cause of earthquakes, and he reasons very ably at considerable length on the subject.\* His idea, however, seems to have been dropped, except by a very few, by whom it is entertained only as one out of several conjectural causes. Now if, as must now and then happen, fissures open in the bed of the sea, by the action of earthquakes and close again after a few seconds or minutes, it follows that a large body of water will rush down and be imprisoned, and come in contact with the fused matter below. This water will necessarily be converted into steam, which will only remain quiescent as long as it is everywhere surrounded by a resistance greater than its own expansive force. If the formula approximates towards the truth, unless the resistance amounts to a thousand tons per square inch or thereabouts on every side, in certain cases an explosion will take place of sufficient force to account for an earthquake or volcanic eruption, as the case may be. In reading accounts of volcanoes and earthquakes, it will frequently be observed that *hot water* and *steam* are ejected, to say nothing of the *hot water* and *steam* which notoriously issue from boiling springs and geysers. The writer has made a considerable collection of such cases. There is then plenty of direct proof of the existence of steam in the bowels of the earth, and steam will not be idle if it can find any point of less resistance than its own expansive force. Therefore, in considering the cause or causes of earthquakes, volcanic explosions, and upheavals of strata, you cannot get rid of steam. For let us look from whatever point of view we will the pressure of saturated steam must be enormous long before it reaches the temperature of 3000 degrees.

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SIR :—The figures quoted by Mr. Peacock, in *The Artizan* for January, [*Jour. Fr. Inst.*, vol. xlviii. page 123,] from a table of mine in *The Artizan* for November last, are not to be regarded as independent data respecting the temperatures corresponding to various pressures of high pressure steam. They are merely a few of the results of a formula which I deduced from M. Regnault's experiments, and published in 1849; and they may be regarded as practically identical with the results of those experiments.

W. J. MACQUORN RANKINE.

Glasgow, January 1864.

\* Phil. Trans. R.S. 1760. Vol. II, p. 447, &c.