and part of the bower cables, would be removed to section No. 2; the sea stores to No. 4; and the weights reduced at both extremities.

The excess of weight would not only be considerably reduced in the fore extremity, by the proposed alterations, but at sea, if desirable to lighten this part as speedily as possible, a regular decrease, in a 74 gun ship, of two tons per week, may be calculated on, till the expiration of half the cruise, when the fore bread room would be cleared.

By a minute inspection and measurement of the different parts, and a correct calculation of the different weights and their bulk, the distribution may be made with great exactness.

Removing the anchors where they will stow perfectly clear of the ports, and similar to the sheet and spare anchors, will also leave the round of the bow perfectly clear, and remove every impediment to its being better fortified.

[*Quarterly Journal*.]

Experiments and Observations on some of the Phænomena attending the sudden expansion of compressed elastic Fluids. By PETER EWART, Esq.*

HAVING occasion, about seven years ago, to make some experiments on a high pressure steam engine of the estimated power of nine horses, in the boiler of which the elasticity of the steam was equal to sixty pounds (including the atmosphere) on the square inch, and, consequently, the interior temperature about 290° of Fahrenheit, I applied the bulb of a thermometer close to the opening of the safety-valve, while the steam issued from it in great quantity, and it stood steadily at 160°. The engine being in motion, and the steam, after having passed through the cylinder, escaping to the atmosphere by a perpendicular pipe four inches in diameter, and five feet in height, I applied a thermometer to the steam as it issued from the top of that pipe, and found the temperature to be 212°.

Finding the temperature of the issuing steam only 160° at the safety valve, close to the boiler, and 212° after it had passed to the distance of five feet from the boiler, I constructed an apparatus (fig. 1.) for the purpose of ascertaining whether, under certain circumstances, the temperature of the steam increases after it has issued from the boiler. I had an opportunity (in March 1823) of applying this apparatus to the high pressure steam boiler of Mr. Philip Taylor, at Bromley, near London. A is an iron pipe of three quarters of an inch bore, connected with the boiler, and terminated by a stop-cock B, the area of the opening of which was the same as that of the pipe. The end of a copper tube C, two inches diameter, and sixteen inches long, was screwed to the cock B, so as to be steam tight. To this tube was adapted a thermometer D, so that the bulb stood directly opposite the centre of the opening of the cock B, and at the distance of an inch and a half from it. The opening in the side of the copper

* This article consists of extracts from two papers read before the Literary and Philosophical Society of Manchester;—communicated by the author.

tube, through which the stem of the thermometer passed, was made steam tight. Another thermometer E was fixed in the same manner,

Fig. 1.

near the extreme end of the copper tube, which end was quite open to the atmosphere. The elasticity of the steam in the boiler being equal to fifty-eight pounds, including the atmosphere, on the square inch, (the internal temperature consequently about 235°) and the cock B fully open, the thermometer D stood at 212° ; while E stood at 232° , showing an increase of 20° of temperature at that end of the copper pipe. The tube being removed, another copper tube C (fig. 2.) of the same diameter, and nine inches long, was screwed to the

Fig. 2.

same cock B. This tube was furnished with a thermometer D as in the last experiment. The end E of the copper tube was stopped by a flat plate, excepting a hole $\frac{1}{12}$ th of an inch diameter, in the centre

of the plate. The steam in the boiler being about the same force as in the last experiment, and the cock B being opened, the thermometer D stood at 292° ; while another thermometer, having a very small bulb, held near the hole E, as the steam issued from it, stood at 185° . A small glass tube F, open at both ends and drawn to a fine point at the top, was placed so that the top of the tube was in the jet of steam issuing from E, while the lower end of it was immersed in a trough of mercury. The thermometer D standing at 292° , as before, the mercury rose twelve inches in the tube F. The mercury stood highest in F when it was near to E.

In August 1825, I had an opportunity of making some experiments on the sudden expansion of atmospheric air at Messrs. Fairburn and Lillie's foundry in this town, of which the following was one. A (fig. 3.) represents a transverse section of a cylindrical horizontal pipe, seven inches in diameter, which conducts air from a blowing apparatus to a furnace. B is an inverted glass syphon inserted into the side of a pipe A. A round hole, $\frac{1}{10}$ th of an inch diameter, was made in the opposite side of the pipe, to which was adapted a conical

Fig. 3.

tube of tinned iron CD, 5.4 inches long, and whose internal diameter was $\frac{1}{4}$ inch at C, and 1.05 inch at the extreme end D, which was open to the atmosphere. To the lower side of this conical tube, two perpendicular glass tubes, E and F, were attached, their upper ends opening into CD, and their lower ends being immersed in a trough of mercury. The centre of the tube E was $\frac{1}{5}$ inch from the inside of the pipe A, and the centre of F was 2.2 inches from the centre of E. Some mercury having been put into the inverted syphon, and the blowing apparatus being set to work, (the air passing through A at the velocity of forty-five feet per second,) the mercury stood at 1.8 inch higher in the outer than in the inner leg of the syphon; while the mercury in the trough rose 2.7 inches in the tube E, and only .4 inch in F; showing a greatly diminished pressure in the air at E, while its pressure was much increased in passing from E to F. On the internal pressure in A being increased, the mercury rose higher in nearly the same proportion in E and F.

In the *Annales de Chimie et de Physique* for September 1827, there is an account of a fact observed in 1826 by Mr. Griffith, engineer, at Fourchambaut, which is described as consisting of this:—That if air strongly compressed in a reservoir escape by an orifice in a plane surface, and if a plate or disk of metal be presented to the jet of air, that plate is attracted to, instead of being repelled from, the flat surface from which the air issues.*

* This fact had been previously observed in October 1824, by Mr. Roberts, a member of the Manchester Philosophical Society.

In the same article in the *Annales de Chimie*, there is an account of some experiments and their results on the issuing of compressed steam.

Some of these results agreeing, and some being at variance, with those exhibited in figs. 2 and 3, I constructed the following apparatus for the purpose of examining more distinctly the effects produced by the expansion of compressed air under similar circumstances. A (fig. 4.) is a longitudinal section of a perpendicular pipe of

Fig. 4.

F is an inverted glass syphon inserted into the centre of DE, and G is a similar syphon inserted into DE, at the distance of 1.5 inch from F. H, I, and K are three small glass tubes, open at both ends, inserted into BC, and having their lower ends immersed in a trough L of coloured water. M an inverted syphon inserted into A. The centre of the tube H was at the distance of .9 inch; that of I, 2.1; and that of K, 3.4 inches from the interior side of A. The space between BC and DE being adjusted to .2 of an inch, some mercury being put into all the inverted syphons, and the compressing apparatus being set to work,—the syphons G and M indicated each an interior pressure of 1.25 inch, and the syphon F, 1.3 inch of mercury. The coloured water rose 9. inches in H, 2. inches in I, and .5 inch in K. On the interior pressure in A being increased, the coloured water rose higher, in nearly the same proportion, in H, I, and K; and the amount of the downward pressure on DE still much exceeded that of the upward pressure from A.

Some of these results being still at variance with some of those described in the article of the *Annales de Chimie*, already quoted, I prevailed on Mr. Dalton to witness a repetition of the experiments (fig. 4.) in November 1828, and he was satisfied that the results were correctly stated.

Various explanations have been proposed of some of the phenomena which I have described.

It has been supposed that the ascent of the mercury in figs. 2 and 3, and of the coloured water in fig. 4, is occasioned, not by the rarefaction of the fluid in contact with the upper ends of these tubes, but by the particles of fluid in the tubes (whether these particles be of air, water, or mercury) being drawn or sucked out by some kind of lateral action of the issuing fluid. But if there were any action of that kind, its effects would be apparent in the inverted syphon (fig. 3.); and the mercury in the leg next to A (in which the air was moving at the rate of forty-five feet per second) would have been elevated instead of being depressed.

I applied an inverted syphon to the air reservoir of a similar blowing apparatus, in which the interior pressure was equal to 33.5 inches of mercury (including the atmosphere,) while another syphon was applied to the conducting pipe, as in fig. 3, at the distance of twelve feet from the reservoir. The air was passing along the pipe with the velocity of forty-eight feet per second, and the interior pressure was only 1-268th part less in the conducting pipe than in the reservoir.

Explanations of the low temperature of high pressure steam, at the place where it issues, have indeed been proposed, without any reference to the rarefaction of the steam at that place. It has been held by some, that the steam issues with so great a velocity at that place, that it has not time to give out its heat; that unless part of the steam be condensed into water, little or none of its heat can be given out; and it has been asserted that when the hand is presented to such steam, it remains dry. Others have held, that the current of steam carries with it a current of air, attracted in some manner to its sides, by which the bulb of the thermometer is cooled.—My hand, however, has always been wet by the steam when presented to it; and in most of the experiments which I have made, the bulb of the thermometer was surrounded with steam; so that it could not be affected by any external air supposed to adhere to the sides of the current of steam.

That the temperature of high pressure steam, on being released, should come down to the temperature of steam of atmospheric pressure, is what might be expected. But how it instantly falls so much below 212° requires some explanation.

There are three circumstances to be observed in the foregoing experiments, which appear to require particular attention.

1st, The reduced pressure takes place in the greatest degree near the point where the air or the steam is released from compression. (See figs. 2, 3, and 4.)

2ndly, After the air has been suddenly expanded, it quickly recovers a large portion of its former density. (See figs. 3 and 4.)

3dly, A portion of elastic fluid of given density is displaced by another portion of the same fluid, of much less density than that of the fluid which has been displaced. (See figs. 3 and 4.)

In October 1822 I read a paper before this Society, giving an account of some experiments which I had then made on this subject, and suggesting an explanation of the results on mechanical principles. I did not offer it then nor do I offer it now, with the expectation that it will be generally considered as satisfactory. All the experiments, however, which I have made since that time, admit, as it appears to

me, of that explanation: and I have had the satisfaction to find that it has been adopted by several very good experimenters.

Such as it is, I beg leave to offer it again after an interval of six years, to the consideration of this Society.

If we suppose A and B (fig. 5.) to be two equal balls of lead at-

Fig. 5.

tached to the opposite ends of an elastic spring; and if we suppose the spring, in the position of A and B, to be in a neutral state, that is, to have no tendency either to expand or collapse.

If we next suppose the balls to be compressed together as at C and D, and then suddenly set at liberty, they will, by the joint action of elasticity and momentum, spring out, not only to the distance they were at originally as at A and B, but to a distance as at E and F, as much beyond their original distance as they had been compressed within it. After having been separated to that distance, they will collapse and vibrate to and fro for a time.

Now if elastic fluids such as air and steam, consist of separate particles, we know that these particles are kept asunder by an elastic force, the same in effect as if steel springs were interposed between them; and we cannot doubt that such particles have momentum like all other ponderable matter; neither can I see any reason to doubt that the sudden expansion and contradiction of their distances must be similar to those of the leaden balls.

Thus, if we suppose A and B to be two particles of atmospheric air, at the distance they are in the atmosphere; if they be compressed as at C and D, and suddenly released, they will be separated as at E and F, and produce all the effects of a corresponding rarefaction or dilatation. It is true they may not separate so far as at E and F, because of the interruption they meet with from other particles of air in the atmosphere; but it is reasonable to conclude that they will separate beyond the distance of A and B. After being separated to their greatest distance, they will collapse, not by the reaction of the elastic force between them, as in the case of the leaden balls, but the similar action of the elastic force of the particles of air into which they are projected.

In this view of the phenomena, by the combined mechanical action of elasticity and momentum, the low pressure of highly compressed steam, at the place where it is released, becomes only what is due to its mechanical dilatation,—the consequence of its previous compression. And, accordingly, it is found that the more it is compressed the more dilated and the colder it is when suddenly released.

[*Philosophical Magazine,*