LIQUID AIR AND EXPLOSIVES.

By FREDERICK H. MCGAHIE.

A FASCINATING realm has been recently opened to science for exploration. It is governed by a magician whose delight is in paradoxes. With the touch of his wand substances appear to reverse those natures to which we are accustomed, for under the influence of liquid air, lead acquires a degree of elasticity, rubber becomes extremely brittle, roses grow friable petals, mercury is fashioned into hammers, and ice possesses a fiery heat. Our obligations to Charles Tripler are well known. His persevering work has taken liquid air from the list of expensive scientific curiosities and placed it at the service of all investigators. He has made it a commercial article, whose application to practical purposes will call forth the ingenuity of many minds. Of its value to pure science there can be no doubt. Its worth measured by the dollars of the commercial world lies with the future for verification. A magazine writer has credited Mr. Tripler with a claim that amounts to perpetual motion from a financial point of view. This claim is that a given amount of liquid air utilizing the heat of the atmosphere to change it into gas with expansive force can be worked in a suitable engine to produce a larger amount of liquid air, the surplus becoming available for production of power for manufacturing purposes. Free fuel would certainly revolutionize engineering practice. Engineers are always open to proof, but are meanwhile trusting to their yet unrevolutionized thermodynamic conceptions, and are designing and specifying costly boilers to set free the energy locked up in coal, for which article the "coal barons" are untriflingly demanding their stated amount of lawful currency. In Europe, some attention has been paid to the proposition of employing liquid air in explosives. It is reported that the German War Office is now prosecuting a series of experiments relative to its utility in that direction for military purposes. Our present knowledge of the matter points to but a limited degree of success. Theoretical considerations give a value to liquid air for explosive work that would appear to be balanced largely by the serious objections obtruding themselves persistently in practical tests.

A brief summary of the general phenomena of explosives will be of aid in viewing the theoretical side of the case. Chemical action occurring in a minute interval of time, and evolving considerable heat and a large volume of gas, underlies the explosive reaction. Heat is furnished by combustion and by the decomposition of endothermal bodies. The principal examples of combustion to be found in the study of the practical explosives are the formation of CO , CO_2 , and H_2O . When the oxygen is furnished by the breaking up of NO_2 , this action itself evolves heat to augment the heat furnished by combustion. The explosive reaction having been originated, the tendency is to produce the maximum amount of heat through the fullest oxidation possible to the system. One pound of carbon burning to CO_2 gives off approximately 14,500 heat units whose energy equivalent is 11,281,000 foot pounds; 1 pound of hydrogen in forming H_2O evolves some 62,000 heat units, representing 48,236,000 foot pounds. It is manifest that these reactions furnish plenty of energy for man to direct into the performance of useful work. They occur in the furnaces of boilers, but at a rate that removes such action far from the explosive one in which time is measured by the thousandth and the millionth of a second. On account of its volatility we may exclude liquid air from the gunpowder field, where a long time may elapse between the manufacture and the gun. It is among the high blasting explosives that the attempt is being made to introduce the substance. The characteristic of this class is detonation. In gunpowders combustion occurs progressively throughout the explosive, so that the pressure mounts from zero and allows mechanical action to occur along the lines of least resistance, and by physical details like intimacy of mixture, density, shape and size of grains, we are enabled to control the pressures developed to meet the various problems of gunnery. Detonation arises from a wave action propagating the explosion so rapidly through the mass that it may be considered instantaneous, the result being that the whole volume of highly heated and expansive gases is evolved in the original volume of the explosive itself, and the highest possible pressure of the system is thereby produced.

The result is a shattering blow that has little regard for the lines of least resistance. Detonation may be modified somewhat in the nature of its work in accordance with the practical limits of getting large blocks of material or crushing it into small fragments capable of being handled easily. It is probable that detonation may be provoked in any explosive by suitable means. In practice the gunpowders do not pass from their proper explosion to detonation through accidental causes, while the high explosives tend always to detonation if the original source of decomposition has not been sufficient to provoke it at the start. We may say, in the language of calculus, that gunpowders explode in Δt , and high explosives detonate in Δt .

Consider 1 pound of carbon in the form of an impalpable dust distributed uniformly throughout sufficient air to insure complete combustion, the proper amount containing 2.666 pounds oxygen and 8.927 pounds nitrogen. Upon ignition of this mixture inclosed at atmospheric pressure in a strong vessel, the reaction would occupy but a minute fraction of a second and would be complete before any appreciable amount of heat could be transmitted to the walls. The resulting products would be 3.666 pounds of CO_2 and the original 8.927 pounds nitrogen. The explosion taking place at constant volume, the proper specific heat for the mixture of gases after explosion is 0.172, so that $0.172 \times 12,593 = 2.166$ heat units would raise its temperature 1°F . Since the action gives off 14,500 heat units, the total increase of temperature becomes approximately 6,700 $^\circ \text{F}$. The volume occupied by the carbon at the start is negligible in comparison with that of the air, so that the volumes before and after explosion are equal, the nitrogen remaining unchanged and the oxygen being replaced by an equal volume of CO_2 . The theoretical pressure is due accordingly to the raising of a perfect gas at constant volume from the initial temperature taken as 32°F . to $6,700 + 32 = 6,732^\circ \text{F}$. Pressures being under these conditions proportional to the absolute temperatures, we obtain the

figure of 14.6 atmospheres absolute. The coal dust explosions that do occur are more dangerous for carrying flame than for destructive effects, since the supposition of an impalpable dust suspended uniformly in the proper amount of air is not at all realized and the combustion occurs slowly enough to permit expansion of the gases before any appreciable pressure is produced. The light combustible dusts guarded against in flour mills and grain elevators give a better approximation to the conditions. It is well known that such explosions wreck buildings in addition to igniting combustible material.

In the above example the nitrogen is a drawback in occupying space and absorbing heat. Considering it removed, the 14,500 heat units are available for increasing wholly the temperature and pressure of the 3.666 pounds of CO_2 . At constant volume the increase of temperature is 23,000 $^\circ \text{F}$. and the pressure becomes 47.8 atms. absolute. To employ this case in practice we would have to select some combustible gas to add to the oxygen in order to attain a homogeneous mixture. Many of the hydrocarbons would do. Marsh gas may be selected as representing the chief ingredient in mine gas explosions. With pure oxygen

One pound CH_4 contains 0.75 pound carbon and 0.25 pound hydrogen. The complete oxidation of these gives 26,375 heat units. To break up the pound of CH_4 about 2,160 heat units are required, and to raise the $2\frac{1}{4}$ pounds of water from 32°F . to steam at 212° (to have our products all gaseous at atmospheric pressure in the calculations) 2,580 units are needed. This leaves about 21,700 units available for producing pressure, which figures out as 34.3 atms. absolute or 490 pounds gage. Such pressures are, however, of no value for explosive work. The first idea would be to compress the mixture heavily, so that the multiplication of the initial pressure would take us into the region of high pressures. The difficulties, cumbersome, expense, and limitations of such a system are apparent. But there are supplies of highly condensed oxygen in many salts, and the practical explosives consist of intimate mechanical mixtures, like black powder, of a combustible and an oxygen-bearing salt, and the explosive compounds, like nitroglycerin, in which combustible and comburent exist side by side in the same molecule. Thus 1 pound of nitroglycerin occupying but 17.3 cubic inches contains by weight 0.158 carbon, 0.022 hydrogen, 0.185 nitrogen, and 0.634 oxygen, and, when exploded in its own volume, has a theoretical pressure of over 30,000 atmospheres. It is to be noted that these theoretical pressures run considerably above measured ones, since specific heats are increasing functions of the temperature and chemical dissociation limits the reactions and temperature attainable to the vicinity of that temperature at which the completely oxidized products cannot exist. Such calculations are, however, of value in indicating the relative effects of which various explosives are capable.

It is as a source of highly condensed oxygen that liquid air enters into the case. The lower boiling point of liquid nitrogen permits the concentration without material loss of liquid air to a point at which it contains 75 per cent. by weight of oxygen wholly available for explosive purposes. Nitrate of potash has but 39 per cent. of available oxygen and sodium nitrate 47 per cent. It is better than nitroglycerin with its 63 per cent. In addition the nitrogen, in passing from the liquid to the gaseous state, increases the volume of gaseous products and adds thereby to the pressure, compensating in a degree for the heat absorbed by it. This highly oxygenated liquid has a density about that of water and yields a powerful explosive upon admixture with some combustible material permitting it to soak in well. Those who have witnessed Mr. Tripler's experiments have seen sponges, felt, cotton, and such bodies dipped into liquid air flash off upon ignition like so much loose gun-cotton. When slightly confined, a proper primer will produce detonative action similar to that of the dynamites. Indeed, the broken tube pictured in illustration 17 of Prof. Peckham's article contained in the April 29, 1899, SCIENTIFIC AMERICAN SUPPLEMENT exhibits most violent effects obtainable upon simple ignition in an open tube of a wad of cotton saturated with liquid air. This makes the process of manufacture a simple, safe, and cheap system. Into a prepared cartridge, containing some combustible like pulverized coke or some weak nitro-compound arranged to allow rapid saturation, the oxygenated fluid is poured. One trouble would appear at least at this stage. Liquid air produces a most serious burn that heals very slowly. Workmen who can blow themselves up with dynamites with more or less frequency will give many opportunities for studying such burns.

Its volatility is a decidedly bad, if not fatal, feature. The present practice is to place the liquid air in tin cans packed in felt. Such a can holding 3 gallons has taken 10 hours for complete evaporation. Prof. Dewar has brought forward a double-walled glass receptacle in which a vacuum is formed between the walls. This device multiplies the figures of felt-protected cans five or six times. But in case of delivery from a central station, and on the assumption that practical cans based upon Prof. Dewar's idea are feasible, the consignee would naturally expect to have something outside of a can delivered to him, and the above figures must be materially reduced. Most places where any amount of blasting explosives is used are located in out-of-the-way places. Transportation by freight is out of the way, and express service is a prohibited luxury. Even assuming it could be delivered commercially, liquid air would have to be used up within a few days at the outmost, and no contractor would even consider the proposition of being dependent several times a week upon the timely delivery of explosive material. The only way out of the matter is to install a plant on the spot to deliver liquid air as needed. This limits our case to contracts of some degree of magnitude. In extensive blasting the economical policy is to fire many holes at the same time. No protecting envelope that would be of value is permissible for the charge, since enlarged bore holes represent increased expense, and it is necessary that the charge should be packed in closely. The tamps would not stay in long under the pressure of the evaporating oxygen. What would occur would be that by the time the holes had been loaded, the wires connected up, and the men removed to a safe place, there would be no oxygen left in the charges.

Some European tests have found little value in the commercial utilization of liquid air for explosive work. I quote from London Engineering: "The process has been tried experimentally, but on a commercial scale, at the Penzberg coal mine near Munich. The powdered carbon mixed with one-third its weight cotton wool is placed in a cartridge case of stiff paper and the liquid air poured over it. The mixture maintains its full explosive properties for 5 to 10 minutes, but after that falls off in power, and at the end of 15 to 30 minutes loses all its explosive properties." The liquid air was supplied by the European investigator, Dr. Linde, from his apparatus for liquefying air and contained around 50 per cent. oxygen. The effects of the fresh explosive were very powerful and comparable to those of dynamites.

PHOTOGRAPHING BACTERIA.*

By EDMUND J. SPITTA.

BACTERIA in their natural unstained state are exceedingly small, and for the most part colorless and structureless bodies of protoplasmoidal matter assuming all manner of shapes and having such a high refractive index as to be most difficult to see—even with a magnification of 1,000 diameters—and still more difficult to photograph. Although these little organisms can be artificially stained by solutions of many substances, still each variety seems to have a more or less well marked selective power of absorbing the coloring matter of one or two special dyes in preference to that of any other. Hence, as the photo-micrographer meets with this type of work he must expect not only all varieties of shape, but all varieties of color also.

The difficulty noticed by all photographers in obtaining a well-contrasted print of these little bodies depends solely upon the fact that the dyes with which the organisms are stained do not affect the photographic plate in the same manner and to the same extent as they do the eye. For example, a slide may be a very excellent one from a bacteriological point of view, and owing to the selective coloring of the organism as compared with that of the background, may be of a most impressive nature, yet it will not yield an equally contrasted print. On consideration, the reason for this apparent anomaly is not far to seek. Contrast visually was obtained by differentiation of color rendering between the bacillus and the background, whereas in the photograph it must depend upon what effect each color can cause on the plate. Put another way, contrast visually is due to duality of color rendering, whereas in the print it alone depends upon what amount of differentiation in terms of black and white the colors employed as stains have been able chemically to produce—by deposition of silver—in the emulsion which covers the plate.

The aim of the operator must be to increase the difference in these deposit ratios as far as he possibly can. To understand how this can be effected, the attention of the reader must be directed to the following:

1. Color sensation to the eye is dependent upon the wave length of the light employed. The longest wave gives rise to the red sensation, and the shortest to the violet; intermediate lengths being productive of sensations we call yellow, yellow-green, green, greenish blue, blue and blue-violet.

2. The ordinary photograph is taken by the violet ray, because the usual emulsion is most sensitive to that particular wave length. Plates, however, can be stained so as to be extra sensitive in any one or more colors, but even then with this extra sensitiveness, the action of the violet is always the strongest, i. e., more precipitation of silver—time for time—is produced with violet light than any other color.

3. Ordinary white light consists of a blending in certain proportions of lights of all wave lengths.

4. An ideally perfect monochromatic screen is one that intercepts all other wave lengths save the one it passes. A red screen, therefore, cuts off (really converts into heat) all other rays, save the red ones; blue cuts off all but the blue, and so on. It is difficult to obtain a really monochromatic screen, and impossible to obtain a glass ideally perfect, save perhaps in the case of red glass. It must also be noted that perfection of monochromatism also depends on the strength of the illuminant, that is to say, a screen may be almost perfect with a weak light, but far from perfect with a strong one.

5. The effect of placing two monochromatic screens each ideally perfect, and of the same intensity, over one another would be to cause blackness, such blackness being the more perfect the more intense the screens or the feebler the white light—screens of differing intensity vary in their effect according to such variation, by which is meant an intense red and a feeble green will allow a residuum of red; a strong green and a thin red, a residuum of green, and so on.

6. As ideally perfect monochromatic screens are obtainable with such difficulty, so with ordinary ones another residuum may be left. Red filters often pass a little yellow; blue ones often a little red; green ones occasionally a little blue, and often red; while yellow ones are rarely pure at all, permitting red and green rays to pass to some considerable amount. If, now, a blue passing red be placed over a good green, but one passing a modicum of red, and provided the light be intense enough, a dark, deep red residuum is noticed instead of blackness. This is obviously caused by the green and violet causing darkness, but not sufficient to annihilate the reds from each glass. More green or more violet will often effect the production of complete darkness. In practice, owing, of course, to impurities, it is found that some colors are more antithetical than others. Red and green, for example, usually produce greater blackness than red and orange, a fact which we shall presently explain is made use of at times.

Now with these six precepts before us I hope to be able to show how the photographer can increase the contrast in his negative, and so, of course, in the print which is taken from it. Let it be assumed that he has taken an ordinary photograph of a red bacillus on a white ground, with blue-stained nuclei of cells interspersed about. He finds a flat result, a negative that produces a wretchedly poor print lacking all contrast. Now let him place a fairly strong green screen over the illuminant and use a green-stained plate to shorten exposure. The resulting negative will show clear patches

* From an article on Photo-micrography in The Pharmaceutical Journal.