very wet weather.

While phosgene boils at 46.7°F., which is considerably below ordinary summer temperatures, its rate of evaporation is so slow that it has to be mixed with equal quantities of chlorine in order to set up satisfactory cloud-gas concentrations in the field. This was the manner in which phosgene was employed in cloud-gas attacks throughout the war.

The toxicity of phosgene is over ten times that of chlorine, a concentration of 0.50 mg. per liter being fatal after 10 minutes' exposure. In higher concentrations, which are often met in battle, one or two breaths may be fatal in a few hours.

Phosgene appears to exert its physiological and toxic effects chiefly through the medium of its hydrolysis products—hydrochloric acid and carbon dioxide. Its effects upon the upper air passages of the body, where moisture is relatively small, is therefore comparatively slight. With prolonged breathing, however, sufficient phosgene is decomposed in the bronchi and trachea to produce marked inflammation and corrosion. These effects reach their maximum in the alveoli where the air is saturated with water.

Unlike chlorine, phosgene produces but a slight irritation of the sensory nerves in the upper air passages, so that men exposed to this gas are likely to inhale it more deeply than they would equivalent concentrations of chlorine or other directly irritant vapors. For this reason, phosgene is very insidious in its action and men gassed with it often have little or no warning symptoms until too late to avoid serious poisoning. Generally, the victim first experiences a temporary weak spell, but otherwise feels well and has a good appetite. Suddenly he grows worse, and death frequently follows in a few days.

Concerning the physiological action of phosgene, which is typical of the lung-injurant agents, General Gilchrist says:

After gassing with phosgene there is irritation of the trachea or bronchi; coughing is not a prominent symptom, and disruptive emphysema is practically never seen. After moderate gassing, a man may feel able to carry on his work for an hour or two with slight symptoms, but he may become suddenly worse, may show evidence of extreme cyanosis, and subsequently may pass into collapse. There are records of men who have undergone a phosgene-gas attack and who seem to have suffered slightly, but have died suddenly some hours later upon attempting physical effort.

Pulmonary edema appears very early. This edema is at first noncellular but, after about five hours, leucocytes are found, and later the exudate is rich in cells. After inhalation of phosgene, red blood cells are seldom found in the exudate; later fibrin appears. Physical examination at this time reveals focal patches of bronchopneumonia. At the height of illness edema is the outstanding condition. After the

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second or third day, if death does not occur, the edema fluid is resorbed and recovery follows, barring complication of the bronchopneumonic process.

The important immediate effects of phosgene are practically limited to the lungs. These changes consist of damage to the capillaries. This damage may be noted a half hour after gassing. The capillaries in the walls of the alveoli are markedly constricted and appear collapsed. Later they become dilated and engorged with blood, and blood stasis is the rule. Frequently thrombi form and block the capillaries for some distance, which increases the blood stasis. This dilation and blood stasis in the capillaries is the main cause of pulmonary edema; the latter progresses rapidly from this time on.

A number of theories have been advanced to explain the production of edema. The preponderance of evidence as to the cause of the edema following phosgene gassing is that it is due to local injury of the endothelial cells which results in an increased capillary permeability; the other changes in the blood and in the circulation are secondary to the trauma sustained by the capillary wall.

The injurious effects of phosgene are materially increased by physical exertion. Frequently those parts of the lungs which have not been damaged by the gas would be sufficient for breathing purposes if the body were at rest, but they are not sufficient while the body is in motion, particularly in view of the excess carbonic acid which is formed in the body by the decomposition of the phosgene.

Phosgene is manufactured in industry by the original process of direct synthesis of chlorine and carbon monoxide, as indicated in Chart X. The only change from the original process of making it is the substitution of a catalyst (animal charcoal) for the action of sunlight.

Compared to chlorine, phosgene has the following advantages as a chemical agent. It is:

1. Far more toxic (0.50 mg. per liter at 10 minutes).
2. A little less volatile and more persistent.
3. Greater vapor density (3.5).
4. More insidious in action.
5. Chemically more inert and, therefore, more difficult to neutralize and protect against.

The principal disadvantages of phosgene are its slower physiological action on the body and its inability to discharge itself from cylinders at a sufficient rate for cloud-gas attacks.

In addition to the foregoing, phosgene is relatively easy to protect against and for that reason would probably be displaced in the future by gases of greater toxicity and more difficult to neutralize.

Trichlormethylchloroformate ($ClCOOCCL_3$)

German: "Perstoff"; French: "Surpalite"; British: "Diphosgene"

This gas was first used in the World War by the Germans at Verdun in May, 1916, in retaliation for the French phosgene shell which were introduced in February, 1916.

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Trichlormethylchloroformate is the completely chlorinated methyl ester of formic acid and is obtained by completing the chlorination of the monochlormethylchloroformate (K-Stoff). In studying the chlorinated methyl esters of formic acid, the German chemists found that their toxic properties increased, while their lacrimatory powers decreased, with

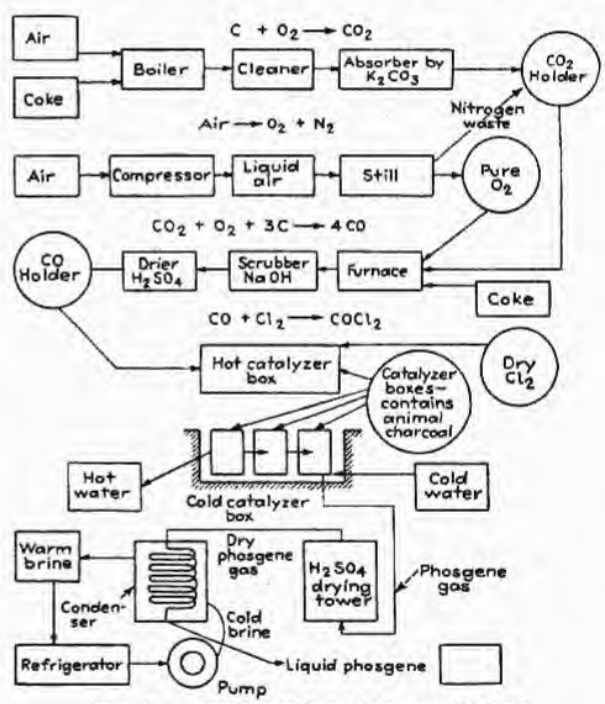

CHART X.—Catalytic manufacture of phosgene (flow sheet).

the addition of chlorine atoms in the methyl group of their molecular structures. Thus, diphosgene, which contains the maximum chlorine atoms, was found to be the least lacrimatory but the most toxic of these compounds and was for that reason substituted for K-Stoff as the standard German nonpersistent lethal gas for shells. An analysis of the gas casualties of the late war indicates that, on the basis of the total

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number of fatalities, diphosgene was the principal *killing* gas used *in shells* during the war.

Trichlormethylchloroformate is an oily liquid of specific gravity 1.65 and a disagreeable suffocating odor. It boils at 127°C. (260.6°F.), giving off a dense whitish vapor 6.9 times heavier than air, which persists on open ground about 30 minutes. At 20°C. (68°F.), its volatility is 26.00 mg. per liter. When heated to about 350°C. (662°F.) or upon contact with moisture, as in the tissues of the body, trichlormethylchloroformate breaks down, yielding two molecules of phosgene, thus: $ClCOOCCl_3$ =