

## Chemical Warfare in World War I: History, Chemistry, Toxicology, Consequences

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Chemical warfare (ChWA) goes back to the antiquities, but modern ChWA began during World War I (WW I) when the German army released chlorine gas in April 1915 on the western front, killing and injuring thousands of Allied (*Triple-Entente*) soldiers. The Allies responded in kind, and ca. 50 substances were used as chemical weapons (ChWPs) in the war. Some of these agents are lethal poisons, while others are irritants such as lachrymators and nasopharyngeal irritants. The "big 3" were chlorine, phosgene, and mustard gas. Mustard "gas" (in fact a liquid) is highly toxic, causes severe chemical burns of the skin and the respiratory tract, and was particularly devastating and terrorizing in WW I. Many models of gas masks were developed for protection from the ChWPs, and some of the models were relatively effective. Nevertheless, ca. 91,000 were killed by ChWPs in WW I and ca. 1.2 million sustained physical injuries, often with permanent debilitating effects. In addition, the psychological effects ("shell shock", "neurasthenia") of ChWA were severe. Moreover, strong evidence has emerged that ChWA may have played a significant role in the etiology of the virus that caused the "Spanish influenza" pandemic of 1918-19 which killed >50 million in 18 months. Overall, ChWA in WW I did not produce the predicted strategic advantage, did not reduce the carnage, nor did it assure victory. Many eminent scientists on both sides participated in chemical-weapons work, e.g., F. Haber (Nobel laureate, 1918), O. Hahn (Nobel 1944), G. N. Lewis, R. Adams, W. J. Pope, H. Hartley, E. Paternò, V. Grignard (Nobel 1912), etc. But some scientists refused to participate, on moral grounds, e.g., E. Rutherford (Nobel 1908), H. Staudinger (Nobel 1953), M. Born (Nobel 1954). The Hague treaty of 1907 unequivocally banned poison weapons but was ignored. Since WW I, other treaties have prohibited chemical weapons (e.g., Geneva Protocol, 1925; Chemical Weapons Convention, 1997) but chemical warfare has continued, often even against civilian populations, e.g., by Spain (in Morocco, 1921-27), Soviet Union (Tambov rebellion, 1921), Italy (Ethiopia, 1935), Japan (China, 1938-39), US (Vietnam, 1960-70s); Iraq (1984-88), Syria (2013-2015). The massive use of ChWPs in WW I was also a stimulating factor for the

Nazis' use of poison gas in the gas chambers of the Holocaust. ChWPs: a tragic legacy of WW I.