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AIR-BORNE INFECTION[1]

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AN increasing awareness on the part of the medical profession of the rôle played by the air in the transmission of respiratory disease makes it seem appropriate just now to survey briefly the recent rapid growth of knowledge in this field. While it has been long known that bacteria can be carried on air currents, the general belief has grown up that certain physical agents such as sunlight, heat and drying are very effective in destroying such air-borne microorganisms. However, during the past few years our knowledge of the wide distribution of bacteria in the air has been greatly increased. Apparently the whole of our atmosphere is contaminated since microorganisms have been recovered from the stratosphere and from freshly fallen snow in the south polar regions. Some of the most striking evidence of aerial transmission of infection comes from the investigation of the spread of certain plant diseases. Epidemics of wheat-stem rust have been shown to be wind-borne from infected areas far distant. Spores of this infection have been found to be carried as much as 1,000 miles in 48 hours and cause an outbreak of the disease a week or ten days later. Similarly, plant viruses have been shown to be disseminated to some extent by wind, at least in an indirect manner, through the agency of leaf-hoppers and plant-lice.

While we have no evidence that any specific agent of human disease is spread through the outside air, except in the case of insect vectors, there is a growing body of data in support of the conclusion that air transmission within enclosed spaces plays an important rôle in the communication of many bacterial and

[1] An address given before the Rochester Academy of Medicine, N. Y., October 6, 1942.

virus diseases, especially those of the respiratory tract. Before proceeding to a consideration of such evidence, I believe it would be of interest in view of our present military state, to review briefly the incidence of respiratory disease in the last war. Of the total number of 108,000 deaths in our armed forces during the period of April 1, 1917, to November, 1918, 50,000 were caused by battle casualties and 58,000 by disease—the usual higher rates of disease to battle casualty deaths, but a much smaller proportion than in previous wars. However, in contrast to other wars, respiratory disease accounted for 47,000 of the 58,000 or 80 per cent. of deaths due to disease in general. This high percentage of deaths from infection of the respiratory tract was of course due to the pandemic of influenza—the fatalities being caused principally by pneumonia. Of particular interest is the fact that probably the majority of the fatal pneumonias were associated with hemolytic streptococcus infection. An increase in the prevalence of the hemolytic streptococcus began with the measles epidemic in the army in the winter of 1917-1918 and when influenza arrived in 1918 the streptococcus was widespread.

The health of our armed forces during the first ten months of this war has been excellent. Respiratory disease, though mild, has however been very prevalent and has accounted for approximately half the total of all cases admitted to hospital for disease in general. While there have been very few deaths from respiratory tract infections, the amount of time lost from duty has been considerable. Surveys of hemolytic streptococcus carriers have revealed a much lower percentage than was present at a similar time during World War I, but among the soldiers suffering from acute infection of the respiratory tract these microorganisms are commonly found. Hence the hemolytic streptococcus presents a menace should the present type of respiratory disease become more severe or should an epidemic of influenza occur. Other pathogenic microorganisms, the pneumococcus, Pfeiffer's bacillus, hemolytic staphylococci, would, of course, play a rôle under such circumstances, but probably a less conspicuous one.

EVIDENCE FOR AERIAL TRANSMISSION OF INFECTION

While the actual proof of infection occurring through air transmission is difficult to obtain except under experimental conditions either with animals or human volunteers, indirect evidence from clinical observation and bacteriological study is accumulating rapidly. Such instances of the spread of measles and chickenpox have been reported under conditions where direct and indirect contact has in all probability been excluded. Furthermore, the direction of the spread has frequently been shown to be that of the flow of the air currents. Wheeler and Duckett Jones[2] have recently reported an outbreak of highly fatal hemolytic streptococcal infection in a rheumatic fever hospital in which the infection spread from the lowest floor to the upper floors immediately above by way of the stairways where an upward air current was demonstrated. While no tests for air-borne bacteria were made at the time of the initial epidemic this was done later and the infecting types of hemolytic streptococci were recovered from the air of the stairways. An instance reported by White,[3] of what would appear to be aerial infection with dust-borne hemolytic streptococcus, was that of a ward attendant who having had no previous contact with this type of infection swept out a room which had been closed for five days following the discharge of a patient who suffered from streptococcal infection. Shortly thereafter the attendant developed an acute throat infection of the same type of hemolytic streptococcus as that producing disease in the patient.

An understanding of the manner in which air-borne infection can occur has been furthered greatly by the concept of droplet nuclei introduced by William Wells,[4] namely, that many small droplets expelled from the respiratory tract evaporate so rapidly that they float in the air for prolonged periods of time and ultimately settle in the dust of the room. Observations by a number of workers, English and Canadian in particular, have corroborated this idea of the manner of air contamination and have shown the importance of the rôle of dust and particulate matter from bed clothes, etc., in distributing pathogenic microorganisms through the air. A detailed account of some of these observations would be of interest, but time doesn't permit of more than a brief mention of some of the most striking findings. (Buchbinder[5] has given an excellent summary of this data in his recent review of the transmission of certain infections of respiratory origin.) Cruickshank[6] was the first to show that the rapid increase in the incidence of streptococcal infection of burns after coming into the hospital was due to cross infection from one or more cases carrying or infected with this microorganism. Furthermore, he was able to recover from the air of the ward considerable numbers of hemolytic streptococci of the same type as those causing the cross infections. Similar studies have been made by Allison and Brown[7] in scarlet fever wards where they found

[2] S. M. Wheeler and T. Duckett Jones, *Aerobiology*, Am. Assn. Advancement of Science Symposium, 17: 237, 1942. Also personal communication.

[3] E. White, *Lancet*, 1: 941, 1936.

[4] W. F. Wells, *Am. Jour. Hygiene*, 20: 611, 1934.

[5] L. Buchbinder, *Jour. Am. Med. Assn.*, 118: 718, 1942.

[6] R. Cruickshank, *Jour. Path. and Bact.*, 41: 367, 1935.

[7] V. D. Allison and W. A. Brown, *Jour. Hygiene*, 37: 11, 1937.

that complications and relapses in scarlet fever patients were due to reinfection with a type of hemolytic streptococcus other than that causing the primary infection. These reinfecting types were recovered from the air of the ward. Allison[8] has also made observations on the spread of streptococcic infection in a measles ward. The cross infections, due to the introduction into the ward of patients carrying the infecting types, occurred in individuals heretofore free from streptococci. Similar observations in diphtheria wards have revealed the presence of virulent diphtheria bacilli in the floor-dust and air at times when cross infections with these microorganisms were occurring.[9] A study by Miles[10] and associates of war wounds infected with streptococcus hemolyticus showed that they were cross infections from types of streptococci present in the air and the dust of the ward. Hare and Willits[11,12] have demonstrated the rôle played by dressings of streptococcal wounds and bed clothes of such patients in the aerial dispersal of hemolytic streptococci. Handling the dressings, especially dry ones, resulted in liberating considerable numbers of these microorganisms, which the authors were able to recover from the air by means of blood agar settling plates. Their finding that bed making of infected patients causes a marked increase in air contamination provides adequate reason for the advisability of isolating such cases.

Experimental studies on air-borne infection with certain pathogenic bacteria has yielded more conclusive evidence for this mode of transmission. Trillat[13,14] showed many years ago that experimental infection of small animals with paratyphoid or fowl cholera bacilli could be accomplished by exposing them to atmospheres containing a finely atomized mist of cultures of these microorganisms. Wells and Lurie[15] found that pulmonary tuberculosis in rabbits could be produced by placing these animals in a chamber into which cultures of tubercle bacilli had been sprayed. Studies on air-borne pneumococci, on the other hand, have yielded little evidence that pneumonia in normal animals is acquired simply by inhalation of pneumococcus-containing droplets. However, if the animals' resistance is lowered by alcoholization, as shown by Stillman and Branch,[16] or if it is suffering from experimental influenzal infection as first demonstrated by Smorodintseff and co-workers,[17] inhalation of pneumococcus-containing atmospheres will result in pneumococcal infection of the lungs.

Another disease whose dispersal has been suspected to occur by way of the air, but in which evidence of aerial transmission has been lacking until recently, is influenza. Repeated attempts made in 1918 to transmit to human volunteers the pandemic influenza, failed. It was not until 1937 that a group of Russian workers headed by Smorodintseff[18] succeeded in producing influenza in human volunteers by allowing them to inhale influenza virus dispersed in fine droplets in the air. Since then aerial transmission of influenza in ferrets has been accomplished.[19,20] More recently, Smorodintseff,[17] Wells and Henle[21] and our laboratory[22] have been able to produce experimental influenza in mice by the air-borne route. The virus employed, having been passed through several hundred mice following its isolation from a human case, was atomized as a very fine mist into a chamber containing the mice to be infected. We found that an exposure of only 15 seconds to an amount of virus diluted 300,000 times in the chamber air sufficed to produce pneumonic lesions in all the mice. A two-minute exposure resulted in death of all the animals. Even with amounts of virus corresponding to a dilution in the air of one to thirty million, all the mice acquired pulmonary lesions. That influenza virus may remain suspended in air in a viable and infective state for relatively long periods of time was demonstrated by introducing mice into virus-containing atmospheres as long as three hours subsequent to atomization of the virus. All the mice became infected.

It seems likely that the virus of the common cold may also be communicated through the air, but of this we have no proof. Neither do we have any information as to the mode of transmission of the newly recognized acute pulmonary disease which has been designated as primary atypical pneumonia. However, one disease, whose communicability through the air had not been heretofore seriously considered, namely, poliomyelitis has recently been transmitted experimentally by the air-borne route.[23]

CONTROL OF AIR-BORNE INFECTION

Measures available and which are now being advocated for the control of air-borne infection fall into

[8] V. D. Allison, *Lancet*, 1: 1067, 1938.
[9] W. E. Cristie and H. D. Wright, *Lancet*, 1: 656, 1941.
[10] A. A. Miles *et al.*, *Brit. Med. Jour.*, II: 855, 895, 1940.
[11] R. Hare and R. E. Willits, *Canad. Med. Assn. Jour.*, 44: 230, 1941.
[12] R. E. Willits and R. Hare, *Ibid.*, 45: 479, 1942.
[13] A. Trillat and R. Kaneko, *Comp. Rend. Acad. de Sci.*, 173: 109, 1921.
[14] A. Trillat, *Ibid.*, 194: 321, 1932.
[15] W. F. Wells and M. B. Lurie, *Am. Jour. Hygiene*, Sect. B, 34: 21, 1941.
[16] E. G. Stillman and A. Branch, *Jour. Exp. Med.*, 40: 733, 1924.
[17] A. A. Smorodintseff *et al.*, *Arkhiv. biologicheskekh Nauk*, V. 52, No. 1, 1938.
[18] A. A. Smorodintseff *et al.*, *Am. Jour. Med. Sci.*, 194: 159, 1937.
[19] A. Trillat, *Comp. Rend. Acad. de Sci.*, 205: 1186, 1937.
[20] C. H. Andrews and R. E. Glover, *Brit. Jour. Exp. Path.*, 22: 91, 1941.
[21] W. F. Wells and W. Henle, *Proc. Soc. Exp. Biol. and Med.*, 48: 298, 1941.
[22] C. G. Loosli, O. H. Robertson and T. T. Puck, *Jour. Inf. Dis.* In press.
[23] H. K. Faber and R. S. Silverberg, SCIENCE, 94: 567, 1941.

two categories—those designed to prevent dispersal of infectious material into the air and those employed or proposed for reducing the infectivity of already contaminated atmospheres, by killing or removing the disease-producing agents.

It has been shown that pathogenic microorganisms —such as the hemolytic streptococcus and pneumococcus—may remain suspended in the air for many hours or days and that their virulence after several weeks' sojourn in the dried state in dust is unimpaired. Buchbinder's[24] observations are especially informative in this respect. Since air currents redistribute the bacteria which have settled in the dust, control of dust has become an important consideration in preventing air contamination. Experiments of Van den Ende[25] and Thomas[26] have demonstrated that the bacterial content of the air of wards or patients' rooms may be greatly reduced by oiling the floors and sweeping with oiled or moistened brooms. Furthermore, they and others have found that treating blankets with a diluted light mineral oil is most effective in preventing distribution of bacteria from the bed clothes. Employing both these measures resulted in a reduction of more than 90 per cent. of air-borne bacteria.

The most important preventive measure is the isolation of the infected patient. This is most effective when single-room isolation is employed. Ward isolation, *e.g.,* segregation of patients suffering from the same communicable disease, is of course much less costly and under certain conditions the only feasible measure, but the grouping of patients with such diseases as measles, scarlet fever or influenza presents the hazard of cross infection of various kinds. For example, scarlet fever patients hospitalized in separate rooms rarely acquire types of hemolytic streptococcus other than that producing the infection, whereas those placed in wards commonly become reinfected with new types and show a much higher incidence of complications. Barriers between the beds and adequate spacing of patients undoubtedly diminish the direct transfer of infected droplets from patient to patient but appear to have little effect in preventing the distribution of dried or dust-borne bacteria.

Another measure for preventing dispersal of bacteria and viruses into the air is adequate masking. I use the word "adequate" advisedly since most of the masks employed in hospitals are relatively ineffective. Jennison's[27] stroboscopic photographs have afforded striking demonstration of air contamination by sneezing and coughing especially by persons suffering from colds, and the effect of proper masking of such individuals. The Canton flannel mask devised by McKhann[28] has been found to be a highly effective and practical one. The relative impermeability of this type of mask even under the great pressure of a sneeze provides good evidence for its effectiveness in preventing the inspiration of infective droplets.

While the institution of such measures provide, a good ground-work for the control of air-borne infection and may under certain favorable conditions be adequate, there still remains the need for reducing the infectivity of contaminated atmospheres. This applies especially to conditions in times of war, under which isolation of infectious patients may be difficult or impossible, and other procedures of preventing air contamination, including continuous masking of ward personnel, becomes impractical. It seems likely that air-borne infection of both bacteria and virus origin depends on the concentration of the infectious agent in the atmosphere. Wells's studies have brought out this point and our own results on experimental transmission of influenza to mice, as well as the observations of others, lend support to this conclusion. If the concentration of the pathogenic material in the air can be kept below a certain critical level, infection only seldom occurs, *i.e.,* the dosage of inhaled pathogens is not sufficient to cause disease—although infection may occur if the dosage is increased by prolonged inhalation of even a small concentration of the infectious agent. Thus any measure which will sufficiently lower the concentration of an air-borne infectious agent should be effective in reducing or eliminating infection. The means which has been most commonly employed for this purpose is ventilation. If a sufficient number of air changes per hour can be secured, the building up of a high concentration of any infectious agent can be prevented. Reyniers[29] has made use of filtered outside air flowing through a system of complete mechanical barriers—consisting of a primary chamber containing the patient and a secondary one connecting with the corridor. While this installation is effective in protecting the patient completely against infection by attendants and bacteria-containing air in the corridor or ward, it is too complicated for use in the average hospital.

EFFECT OF ULTRAVIOLET RADIATION

The bactericidal effect of light has been shown by Buchbinder[5] to be surprisingly effective. Sunlight most of all, but diffused daylight from a blue sky killed 50 per cent. of streptococci and pneumococci

[24] L. Buchbinder, M. Solowey and M. Solotororsky, *Jour. Bact.,* 42: 615, 1941.

[25] M. Van den Ende, D. Lush and D. G. Edwards, *Lancet,* II: 133, 1940.

[26] J. C. Thomas and M. Van den Ende, *Brit. Med. Jour.,* I: 953, 1941.

[27] M. W. Jennison, "Aerobiology," Am. Asn. Adv. Sci. Symposium, 17: 106, 1942.

[28] W. McKhann, data to be published.

[29] J. A. Reyniers, "Aerobiology," Am. Asn. Adv. Sci. Symposium, 17: 254, 1942.

in three quarters of an hour. Hence large window space is most desirable for hospitals. The most potent light effect is that from the ultraviolet end of the spectrum, and the use of specially constructed lamps for the purpose of air-sterilization has now been the subject of study for a number of years. The development of this field has been due principally to Wells[30] and while the number of well-controlled observations on the value of ultraviolet radiation in the control of the spread of air-borne infection is as yet limited, evidence is being accumulated to show that under certain conditions and in certain types of disease ultraviolet radiation is effective. I will mention briefly several studies which seem to demonstrate that the use of germicidal lamps has reduced strikingly the incidence and spread of air-borne infection. One was made by Hart[31] at the Duke University Hospital. For some reason, possibly due to the peculiar locality or the kind of upper respiratory tract flora of the operating room personnel, their incidence of post-operative infection was alarmingly high. Hart made a bacteriological study of the air of the operating rooms and the throats of the surgeons and nurses and found pathogenic bacteria, especially hemolytic staphylococci, very prevalent. He then had ultraviolet lamps installed above the operating tables so that the whole operative field was irradiated. Very promptly the occurrence of post-operative infection was greatly reduced and this was accompanied by a marked diminution in the number of bacteria in the air of the operating room.

A second study has been made at the Cradle in Evanston by Sauer, Minsk and Rosenstern.[32] One ward in this institution was equipped with ultraviolet lights arranged in such a way that each infant's cubicle is protected against the rest of the occupants of the ward by means of a so-called curtain of radiation, *i.e.*, the lamps are placed over the open entrance of the cubicle and throw a screen of light to the floor. During the winter of 1940–41, one of the infants in the control ward contracted a cold. This ward was simply air-conditioned. Within a month or six weeks, the respiratory infection spread throughout the entire ward, affecting every one of the 12 infants. However, in the radiated ward not a single cold occurred despite the fact that some of the nurses in the ward contracted colds during this period. A third ward with doubly partitioned chambers built on the principle of Reynier's mechanical barrier showed only one infection.

A striking instance of the control of chicken-pox with ultraviolet radiation has been reported by Barenberg and associates.[33] In an institution housing 165 infants and children, 97 per cent. developed chicken-pox while not one of the children in the irradiated ward contracted the disease. A recent study of Wells, Wells and Wilder,[34] provides evidence for the control of measles and mumps by means of germicidal lamps installed in schoolrooms. This study, which extended over a five-year period and included observations on a large number of children in three schools, showed that the incidence of measles, in particular, in the irradiated classrooms was very much lower than that occurring among the pupils in the non-irradiated rooms.

The limitations on the use of this form of air-sterilization are that the persons in the irradiated rooms must be shielded from the light which has the sun-burning effect of bright sunlight. This means that in situations other than the special one described in the Cradle installation, it is possible to irradiate only the air above the head. While under these circumstances bacteria and viruses in the upper air of the room can be killed, control of the contaminated lower air depends on air currents which will carry the infected droplets or dust particles up into the stratum of germicidal light. Under certain conditions such partial sterilization of the air may be adequate as pointed out earlier but in other cases more complete killing of air-borne infectious agents may be required. Furthermore, dust-borne bacteria are more resistant to the light than are bacteria carried in droplets. Ultraviolet light is now being employed in a number of different kinds of environments and data should be forthcoming as to its general effectiveness and limitations.

CHEMICAL AIR STERILIZATION

Another method of air-sterilization which has been recently introduced is that of disinfection of the air by chemical means. While the idea of employing bactericidal mists as a method for controlling air-borne infection dates from Lister's original use of phenol sprays in preventing wound infections in operating rooms, until recently no one had succeeded in producing by this method a sterile or relatively bacteria-free atmosphere which could be tolerated by human beings. During the past few years new means of chemical air-sterilization have been devised. These consist in the dispersal of germicidal mists containing the effective chemical agents in such small amounts as to be non-detectable or at least unobjectionable to persons in the treated atmosphere. The compounds

30 W. F. Wells and M. W. Wells, *Jour. Am. Med. Asn.*, 107: 1698, 1936.

31 D. Hart, *Jour. Thoracic Surg.*, 6: 45, 1936.

32 L. W. Sauer, L. D. Minsk and L. Rosenstern, *Jour. Am. Med. Asn.*, 118: 1271, 1942.

33 L. H. Barenberg, D. Green, L. Greenopan and B. Greenberg, "Aerobiology," Am. Asn. Adv. Sci. Symposium, 17: 223, 1942.

34 W. F. Wells, M. W. Wells and T. S. Wilder, *Am. Jour. Hygiene*, 17: 254, 1941.

employed for this purpose are believed to be non-toxic in the minute amounts present in the inspired air.

The initial report on this new approach to the control of air contamination was made by Douglas, Hill and Smith in 1928.[35] They employed a fine spray of a solution of NaOCl and found that in concentrations of one gram of the solution in two million cc of air—complete killing of *B. coli* dispersed in the air could be effected. However, it was not until ten years later that active development of the subject began. In 1938 two papers appeared, one by Trillat[36] concerning the properties of germicidal aerosols—liquid aerosols consist of droplets 1–2 microns in diameter dispersed in air—and the other paper by Mastermann[37] on air-sterilization by atomizing NaOCl solutions. Trillat found that certain germicidal agents which killed bacteria in the test-tube in dilutions not higher than 1:200, were capable of causing death of air-borne bacteria when dispersed in aerosol form in concentrations of one gram of the chemical substance in 5 million cc of air. He believed that the bactericidal activity was due to direct interactions between aerosol droplets and bacterial particles. Mastermann, on the other hand, believed that the high bactericidal effect of NaOCl—he obtained killing effects on air-suspended bacteria in concentrations of one gram of NaOCl in 40 million cc of air—was due to the liberation of HOCl gas from the NaOCl mist and was not an aerosol effect. In the next two or three years, studies by several groups of English workers confirmed and extended Trillat's and Mastermann's observations. Twort and associates[38] employed an aerosol consisting of hexyl resorcinol dissolved in propylene glycol and reported bactericidal effects on certain non-pathogenic microorganisms with extraordinarily small amounts of this material—as little as one gram in four billion cc of air. Pulvertaft and Walker[39] used resorcinol in glycol as well as NaOCl and found both these effective in killing pathogens of the respiratory tract. Andrewes[40] found that influenza virus was susceptible to the lethal effect of these germicidal mists.

Our studies in this field consisted initially in the search for a substance which would fulfil most nearly the requirements for an ideal air-sterilizing agent, namely, that it be non-toxic, non-irritating to the respiratory tract, odorless, tasteless and yet possess a marked and rapid killing action on bacteria suspended in air. Furthermore, it should be relatively inexpensive and easily obtainable. Among the compounds tested which included a number of glycols, it was found that propylene glycol most nearly fulfilled these requirements.[41] This compound, a dihydric alcohol, is closely related to glycerine and has the formula $C_3H_6(OH)_2$.

Studies on the air-sterilizing activity of propylene glycol, which are still in the experimental stage, have shown that this substance, when dispersed as an aerosol or in vapor form, produced rapid killing of large numbers of air-borne bacteria. Pathogenic bacteria of the respiratory tract, pneumococci, hemolytic streptococci and staphylococci, *H. Influenzae* and *H. Pertussis,* were killed immediately when sprayed into atmospheres containing concentrations of one gram of propylene glycol in two to four million cubic centimeters of air. Lesser concentrations of the glycol exerted an immediate and pronounced bactericidal effect although a certain interval of time was required for complete sterilization of the air. Dried bacteria were also shown to be susceptible to the lethal action of the glycol. Adequate controls have been carried out to show that this is a bactericidal and not simply a bacteriostatic effect. Killing of the virus of influenza A was demonstrated by tests in which mice placed in an atmosphere of propylene glycol vapor were found to be protected completely against infection with amounts of air-borne influenza virus that produced death regularly in the control animals.[42]

Knowledge concerning the mechanism of the bactericidal effect of propylene glycol on air-suspended bacteria is still incomplete. However, it has been possible to acquire certain information which has provided the basis for a tentative explanation of the initial phase of this process. It was found that propylene glycol possesses a relatively low germicidal action *in vitro*. Certain bacteria such as the pneumococcus and staphylococcus grow well in broth containing 5 to 15 per cent. of the glycol, but if these microorganisms are suspended in 80 to 90 per cent. propylene glycol they are killed immediately. The means by which a mist of this glycol can produce a lethal concentration in the immediate environment of the bacteria would seem to be limited to two possibilities: (a) direct contact between the glycol droplets and bacterial particles; (b) the production of sufficient vapor or gas by evaporation of the glycol droplets to permit rapid and abundant collision of gas molecules with the bacterial particles. Calculations of the maximum number of contacts between aerosol and bacterial droplets indicate that it would take between 2 and 200 hours for sterilization to occur if this were the mode

[35] S. R. Douglas, L. Hill and W. Smith, *Jour. Indust. Hygiene,* 10: 219, 1928.

[36] A. Trillat, *Bull, de l'Acad. Med.,* 3 Sc. 119: 64, 1938.

[37] A. T. Mastermann, *Jour. Indust. Hygiene and Toxicity,* 20: 278, 1938.

[38] C. C. Twort, A. H. Baker, S. R. Finn and E. O. Purcell, *Jour. Hygiene,* 40: 253, 1940.

[39] R. J. V. Pulvertaft and J. W. Walker, *Jour. Hygiene,* 39: 696, 1939.

[40] C. H. Andrewes *et al., Lancet,* 2: 770, 1940.

[41] O. H. Robertson, E. Bigg, T. T. Puck, B. F. Miller, *Jour. Exp. Med.,* 75: 593, 1942.

[42] O. H. Robertson, C. G. Loosli, T. T. Puck, E. Bigg and B. F. Miller, SCIENCE, 94: 612, 1941.

of action. The exceedingly rapid bactericidal action which we have observed could be accounted for only if the glycol were present in the gas phase. Since propylene glycol is a highly hygroscopic substance rapid absorption of glycol gas by fluid droplets might be expected to occur. Indeed calculations show that with vapor concentrations even below the saturation values of propylene glycol the number of collisions between gas molecules and droplets containing bacteria is sufficient to produce almost instantly a lethal concentration (up to 80 per cent.) of propylene glycol in the droplets. Furthermore, the observed rate of evaporation of droplets of a propylene glycol mist is so rapid that a relatively high vapor concentration is liberated within a second or two. The problem as to how the glycol, once having achieved the effective concentration in the bacterial droplet, kills the microorganisms has not been elucidated.

Before practical application of this method of air-sterilization by germicidal mists and vapors can be instituted, the conditions under which they are most effective should be clearly understood and conclusive evidence of the harmlessness of breathing such chemically treated atmospheres must be secured. That the degree of relative humidity has a marked influence on germicidal action has been recognized by Baker and Twort[43] in the use of their aerosols and has also been found by us in the study of propylene glycol vapor. These air-sterilizing agents are most effective at relative humidities of 40 to 60 per cent. Our studies have shown that the amount of propylene glycol vapor which can be held in the air is inversely proportional to the relative humidity, thus increasing the humidity above the medium range results in a progressive diminution in the concentration of glycol vapor in the air and hence a diminished bactericidal effectiveness. On the other hand, the lessened activity of the glycol vapor in dry atmospheres, even though the vapor is present in relatively high concentrations, may be attributed to rapid desiccation of the bacterial droplets which diminishes their affinity for propylene glycol molecules. We found that temperature also affects this process. Increasing the temperature from 15° to 35° C results in a progressive decrease in bactericidal action.[44]

Other important problems which require elucidation are: (1) the most efficient means of dispersing the chemical agents into the air; (2) the manner in which they can be evenly distributed throughout an enclosed air space; (3) determination of the concentrations desirable and obtainable under varying conditions of ventilation; (4) tests for purity of different lots of propylene glycol or other agents. These problems are being studied.

The question of possible toxic effects from breathing atmospheres containing chemical compounds can be answered only by long-term observations on appropriate animals. There are considerable data in the literature on the toxicity of propylene glycol when administered orally or injected intravenously. Prolonged feeding experiments by a number of workers have shown that rats fed relatively large amounts of propylene glycol for periods of six months to two years apparently suffered no ill effects. Intravenous injection of this substance has shown that it is less toxic than ethyl alcohol. The low toxicity of propylene glycol is quite probably due to the fact that it is metabolized in the body.

We have exposed rats to this glycol in vapor form continuously for a period of 15 months. These animals have shown no ill effects from their sojourn in such an atmosphere and microscopic examination of the lungs and other organs of the body has revealed no changes not seen in similarly aging normal rats. While this is good presumptive evidence for the harmlessness of propylene glycol, we have felt that adequate information on this important point can be obtained only in an animal corresponding more closely to the human being in posture and lung structure. Both clinical and experimental observations indicate that foreign material is eliminated from the lungs of non-erect animals much more readily than it is from those species maintaining a more or less erect posture. Although propylene glycol is readily soluble in the body fluids and would probably be absorbed from the lung, it is possible that accumulation might occur in the lungs of man while an equivalent quantity would be adequately eliminated from the respiratory tract of the rat. Furthermore, we have found that small amounts, one fourth to one half cc of propylene glycol in liquid form, injected directly down the trachea of a rat, produces marked irritation leading to abscess formation and fibrosis. Hence, we have instituted a long-term test in exposing monkeys to propylene glycol atmospheres.

Thus far, little data are available on the practical use of germicidal mists and vapors. This means for controlling air-borne infection has been used to some extent in England, but almost nothing has been published on the results. A brief preliminary report by Harris and Stokes[45] on the effect of propylene glycol vapor in reducing acute respiratory infection in a children's ward suggests that it may be effective.

It would seem probable that the different measures

[43] A. H. Baker and C. C. Twort, *Jour. Hygiene*, 41: 117, 1941.

[44] Unpublished experiments.

[45] T. H. Harris and J. Stokes, Jr., *Am. Jour. Med. Sci.*, 204: 430, 1942.

employed or proposed for the control of air-borne infection, *e.g.*, isolation, masking, dust control, ventilation, ultraviolet radiation and chemical air sterilization, would all prove useful either alone or in combination depending on the particular conditions and the purposes for which they are employed. Extended observations under well-controlled conditions will be required to determine the relative effectiveness of these methods. A study of this nature is now being conducted in an army hospital by the Commission on Cross Infection in Hospitals[46] under the direction of the Surgeon General of the U. S. Army.

OBITUARY

LUDWIG KALLIR

LUDWIG KALLIR, retired chairman of the board of directors and chief engineer of the A.E.G. Union Electric and Manufacturing Company, Vienna, Austria, died on January 7, 1943, in a London, England, hospital. He was 68 years of age. Mr. Kallir had been prominently identified with power generation, transmission and distribution in Central Europe for more than forty years. He was a member of the committee of action of the International Electrical Commission and the chairman of the committee for standard specifications of the Austrian Institute of Electrical Engineers. He represented his country at many international conferences as an official delegate; as such he spent some time in this country during the 1936 World Power Conference. Best known among his many papers and articles in the technical press and in the transactions of engineering societies was his contribution on "Power Transmission" in the well-known European handbook on electrical power edited by Rziha and Seidener.

Born in Austria in 1874, he received his engineering education at the Vienna Institute of Technology and graduated in 1896 with highest honors, and stayed there for the following four years as an instructor in electrical engineering until he joined the Union Electric and Manufacturing Company, Vienna, which was later bought by the A E G Berlin and became as their Austrian branch the A.E.G. Union Electric and Manufacturing Company. In 1908 he was assigned the duties of head of the central station engineering department. Later he became a member of the board of directors, finally its chairman and chief engineer of the company. He retired in 1937 and kept on in Vienna in a consulting capacity until German influence began to overrule first the economic and then the political life of his native country; however, there was no place for an upright man of his kind after the annexation of Austria and he went to England in 1939, where the British Electrical and Allied Industries Research Association, London, gave him an opportunity to keep on in his lifelong devotion to electrical engineering.

The outstanding qualities of Mr. Kallir as an engineer were matched by a charming personality and a deeply humane attitude towards those serving under and with him. Among many other honors which he received was his election as a member of the committee of action of the International Electrical Commission, and his appointments as an honorary consultant to the Austrian Department of the Interior and to the Board of Examiners of the Vienna Institute of Technology. He was a member of the American Institute of Electrical Engineers, the Institution of Electrical Engineers (London), the Swiss Institute of Electrical Engineers, the International Conference on Large High Voltage Systems (Cigré) in Paris, the Austrian Illuminating Society and a former president of the Austrian Committee of the International Electrical Commission and of the Austrian Institute of Electrical Engineers.

ERIC T. B. GROSS

CORNELL UNIVERSITY

HARRY L. DEMBER

DR. HARRY L. DEMBER was born at Leimbach, Germany, on July 11, 1882. Educated at the Universities of Göttingen and Berlin, he was appointed privatdozent at the Technische Hochschule, Dresden, in 1909. In 1914 he was appointed associate professor under Hallwachs. During the same year he was selected by the United German Academies to head a research group for studies in atmospheric optics and atmospheric electricity on Teneriffe.

Upon the death of Professor Hallwachs in 1923 he became professor and dean of the mathematics and physics faculty. When Hitler came to power in 1933 Dr. Dember was retired and awarded a government pension but was told not to enter the physics laboratory. However, in the same year a call came from the government of Turkey to head the department of physics in the University of Istanbul, which he accepted.

In 1941 he decided to come to America, where a daughter and a son had been in residence for some years. After a very long and difficult trip of about 15,000 miles via New Delhi and Cape of Good Hope, he and Mrs. Dember arrived in New York in November, 1941. He came to Rutgers University on January

[46] Board for the Investigation and Control of Influenza and other Epidemic Diseases in the Army, Preventive Medicine Division, Office of the Surgeon General, United States Army.