For health workers, students, and others unfamiliar with techniques of industrial hygiene, a definition of terms and an explanation of the procedures in the technology of air sampling are contained in this talk presented to the chemical section of the 43d National Safety Congress and Exposition, Chicago, October 18, 1955.

Some Basic Principles and Problems of Air Sampling in Industry

By CHARLES D. YAFFE, M.S.

INDUSTRIAL HYGIENE is concerned with everything in the working environment including, of course, the air surrounding the worker. That air, in addition to its normal constituents, may contain foreign substances or contaminants in solid or gaseous form. Unless it is prepared specially in the laboratory, air always contains some contaminants, so it is not strictly correct to say that air is "normal" only when it is "pure." One of the objectives of air sampling is to determine how much of a given contaminant is present in the working atmosphere.

Types of Airborne Contaminants

Airborne contaminants may all be classified chemically. They may be further sorted into two major groups, depending on whether or not they are living matter, such as bacteria, viruses, or molds.

In addition to finding impurities of a chemical nature in air, we also encounter various forms of energy such as light, sound, and radioactivity. These are also parts of the working environment that are of interest to the industrial hygienist. Again, as with airborne substances, these are normally present everywhere, and our interest is primarily with "how much." The measurement of these energy forms, which are sometimes referred to as physical agents, is a broad and complex subject outside the scope of this present discussion, which will be limited to the airborne contaminants referred to as chemical agents.

The methods employed in measuring the amount of a contaminant will depend on the form in which it exists in the air. The forms in which contaminants are found in the air may be classified as dusts, fumes, gases, vapors, and mists.

Dusts and fumes are solid particles which differ in their size and method of production. Dust is produced when solid material is broken up by such operations as crushing, grinding, drilling, and blasting. Fumes, on the other

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hand, are formed by the condensation of solid substances which had been vaporized by heat, such as would occur in welding or furnace operations of various types.

Dusts are generally larger in size than fumes although there are no definite size limitations for either. Large dust particles usually do not present serious hazards to health because, first, since they tend to settle to the ground quickly, they are less subject to inhalation, and, second, if they are taken in, they are usually trapped in the nose and seldom penetrate into the respiratory system to a point where they may remain long enough to cause injury.

Ordinarily, for health purposes we are interested in dust particles smaller than 10 microns in size. A micron is 1 millionth of a meter or approximately 1/25,000 of an inch. A 10-micron particle is about the smallest that can be seen with the naked eye. Most of the dust that is our concern has been found to be between about one-half micron and 3 microns in size although the electron microscope has shown the frequent presence in the air of many smaller dust particles. The electron microscope has also shown that more of this very fine material is retained in the lungs than was formerly believed.

The size range of dust particles produced by industrial operations will vary, depending on both the process and the material involved. The average or median size of industrial dust as determined with the ordinary optical microscope is usually fairly close to 1 or 2 microns.

Fume particles are generally smaller in average size than the dust particle; the maximum size is usually below one-half micron. Fume particles can join together, however, so that with time the average size may increase after formation.

Gases include those elements and compounds that are found only in gaseous form at ordinary temperatures and pressures. Oxygen, nitrogen, carbon monoxide, carbon dioxide, and chlorine are well-known examples.

Vapors are the gaseous forms of substances that also exist in liquid form at ordinary temperatures and pressures. Common materials of this type are water, gasoline, carbon tetrachloride, benzol, and mercury.

Mists are droplets of liquids, produced either by atomizing, as in spray painting, or by condensation, as with water that becomes fog or steam. Because mists are particulate in nature, they may sometimes be collected with the same kind of instruments used for dusts or fumes.

My remarks here omit any discussion of the sampling of airborne micro-organisms, such as bacteria, except to mention that they are often of the same size range as dusts and fumes. Though sampling instruments for those particulates often are capable of collecting airborne micro-organisms, some of the instruments kill the organisms and are therefore considered undesirable in biological sampling studies.

Appraisal of Health Hazards

Before discussing actual sampling methods, we might ask, "Why analyze the air?"

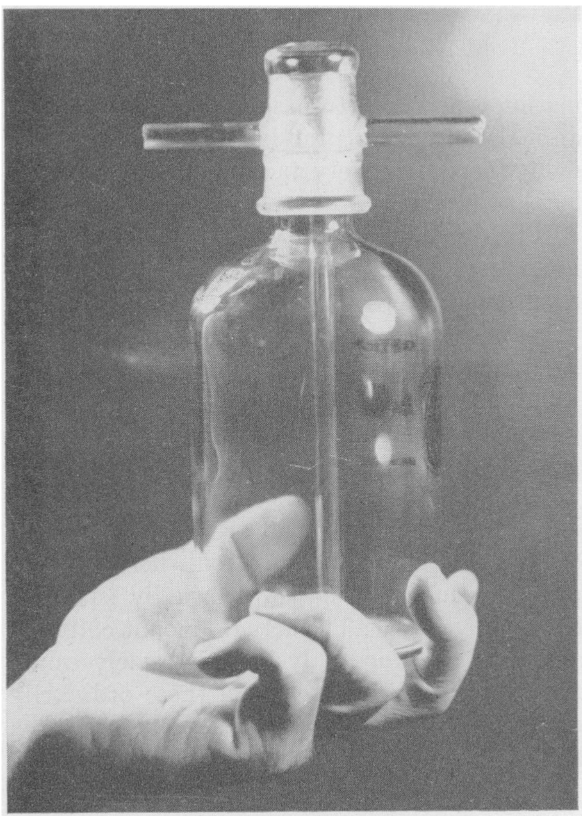
Air often is analyzed for purposes other than to determine health hazards. Industry frequently samples the air in certain locations to determine the presence of leaks which could represent a loss of valuable material or of a fire hazard, an explosion hazard, or a nuisance to the neighborhood. Smoke is measured to determine whether an operation is contributing to a community air pollution problem as well as to find out whether fuel is being utilized efficiently. Information obtained when sampling for one purpose can often be of considerable value for other purposes. For example, concentrations of poisonous materials that are low enough to be breathed safely for an 8-hour work period are without exception far below the lower explosive limit. In other words, if the health hazard is controlled, the explosion danger is eliminated too.

The sampling of air for so many purposes means that the associated problems have been approached independently by various groups, each having different aims, backgrounds, and viewpoints. The resulting interchange of ideas has been beneficial to all concerned. Principles developed for one objective have often turned out to be exactly what was needed to achieve other objectives.

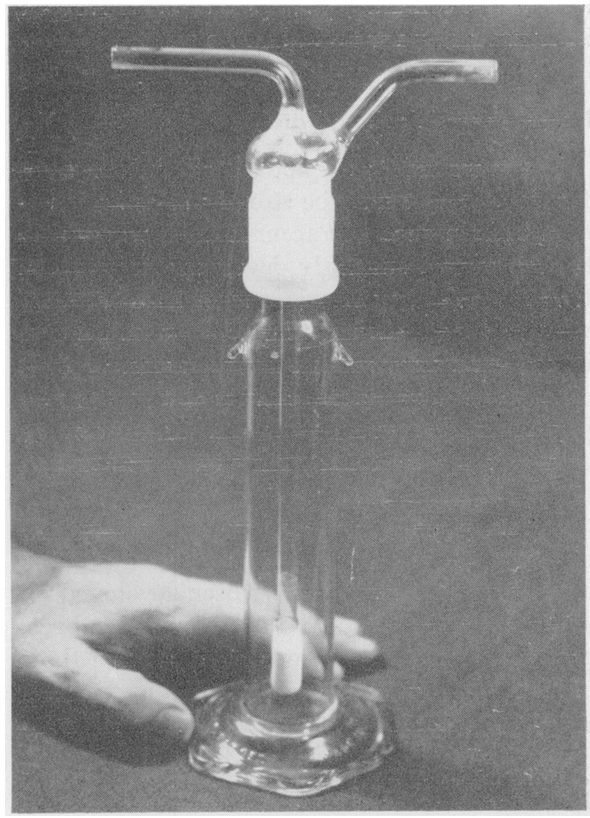
Now, let us consider specifically some of the methods and problems connected with the appraisal of health hazards. The first question is, "How much is too much?" This has always been and probably will continue to be difficult to answer for a long time to come.

It is not a simple matter to determine how toxic a substance is, particularly when the avenue of attack is through the lungs. This is true for several reasons. One is that the amount inhaled will vary according to how much physical effort is involved on the job. A man doing heavy work will require much more air than a man in a sedentary job, and he will, therefore, take in more of any contaminants in the air. Another problem, with dusts, is that the amount penetrating into the lungs depends on the size of the particles. Another complicating factor is the sometimes considerable variation in individual susceptibility. Two men may work side by side for many years in a dusty atmosphere. One may eventually die of silicosis while the other never develops any measurable disability attributable to the dust.

The range of variation is extended even further when we include the person who has an allergic response to even minute amounts of a substance. Another important complication



Evacuated bottle for air sampling.



Fritted bubbler.

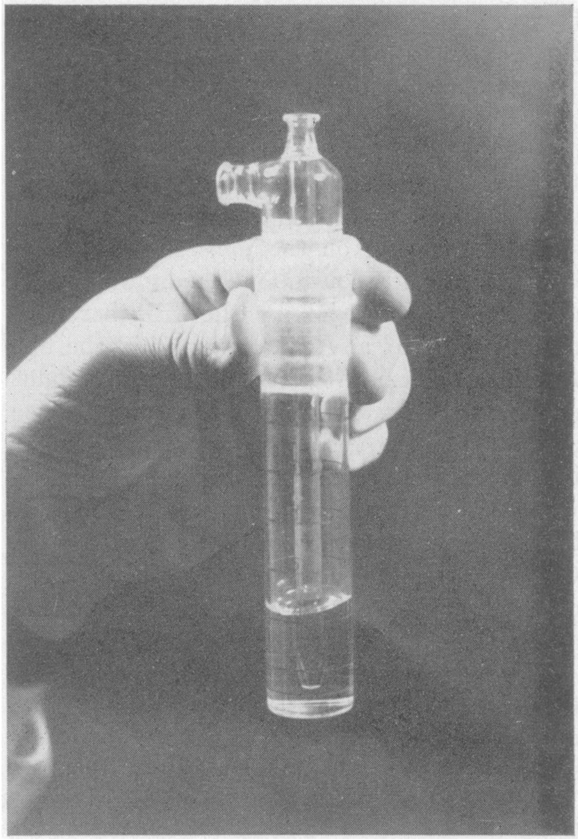
arises when a contaminant has more than one possible effect. For example, suppose it is found that a great number of people work with a given material without discomfort or evidence of injury provided the concentration of the substance in the workroom air is kept below a certain point. Let us assume, however, that an analysis of the death certificates of people who had worked with the material reveals that the cancer rate among the group is twice as high as for people who did not handle the material. The question then arises, "Did this material cause the increase in the cancer rate?" If, and this is sometimes a big "if," the relationship is clearly proved, the next and more difficult question is, "How much of this material is necessary to cause cancer and how long must the period of exposure be?" Fortunately, most materials do not present such complex problems.

We frequently do have the problem, however, of distinguishing between what is acceptable exposure for short periods of time and what is the maximum amount of the substance that can be safely tolerated 8 hours daily, 5 days a week, and, where community air pollution is involved, 24 hours a day for an indefinite period.

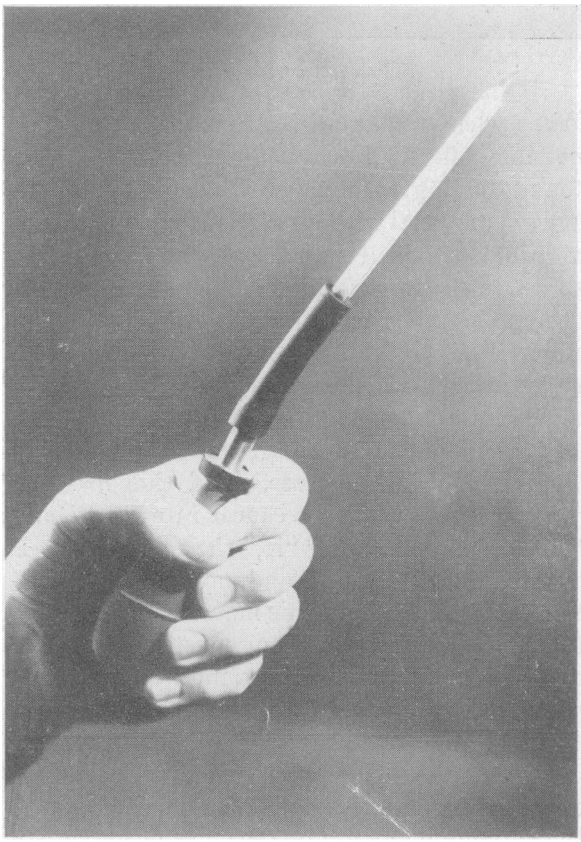
Negative and Positive Data

Toxic materials do not all act in the same fashion. Some may be stored in the body until a certain excess is accumulated, whereupon the individual suddenly develops symptoms of toxicity. Other materials may be eliminated without injury occurring unless the initial dose is large enough to cause immediate effects. Still others may cause definite harm directly in proportion to the amount absorbed. Recovery may or may not occur, depending on the nature of the damage inflicted.

Actually, despite the difficulties in working out recommended standards for substances, much useful information has been developed for a number of elements and compounds, and reasonably satisfactory benchmarks have been established for many others. Each year our knowledge becomes more precise. The information comes both from laboratory research on animals and from practical experience in the field where the safety factor is put to the test by people at work.



Midget impinger.



Carbon monoxide sampler.

It is here that air sampling provides its maximum usefulness whether the environment is hazardous or not. It is as important to measure what is safe as to measure what is dangerous, for the objective is to provide healthful surroundings, and these must be defined. For this reason, negative data are at least as valuable as positive data.

Since different substances have different toxicities, the amounts that are dangerous will differ. The quantities involved where air sampling is concerned, however, usually have one thing in common: The actual amount collected and available for analysis is extremely small. More precise techniques than those ordinarily needed in analytical procedures, therefore, often have to be employed.

I am reminded at this point of 99.44 percent purity. Let us consider the 56 one-hundredths of 1 percent of an airborne impurity such as, say, carbon monoxide. Concentrations of gaseous contaminants are usually expressed as parts per million. One percent equals 10,000 parts per million; therefore, 0.56 percent is equal to 5,600 p.p.m. A person breathing air containing that much carbon monoxide would die in less than an hour.

The maximum acceptable concentration for carbon monoxide for an 8-hour exposure is 100 p.p.m., or 1 one-hundredth of 1 percent. Thus, so far as carbon monoxide is concerned, the air must be at least 99.99 percent "pure."

While carbon monoxide is a dangerous adversary, which must be treated with great respect because it is odorless and colorless, there are other far more poisonous gases. The allowable limits for arsine, phosphine, and ozone, for example, are much less than 1 p.p.m.

Size and Type of Sample

The amounts of some solid materials which must be measured as dust or fume are also exceedingly small. As an example, the recommended limit for 8 hours' exposure for cadmium is 0.1 milligram per cubic meter of air. Or, in units easier to visualize, the limit would be approximately 1 ounce in 10 million cubic feet of air. Fortunately, analytical techniques do not call for an ounce of material. Sampling equipment capable of handling 10 million cubic feet of air in a reasonable time interval might lack portability, to say the least. As a matter of fact, laboratory methods are so sensitive that we can readily determine whether the limit for cadmium is exceeded by analyzing the amount removed from 20 to 30 cubic feet of air. The same is true for most other particulates.

The amount of a contaminant in the workroom air may vary considerably during the cycle of operations. Consequently, we are often interested in extremes of exposure as well as in the average exposure since very high concentrations for a short time may sometimes cause trouble even though the average for the day is not excessive. Therefore, we need to collect two different classes of samples: one for long periods to measure the average exposure, the other for short periods to give information about the fluctuations in concentration.

The time required to obtain an accurate evaluation of the average exposure will, of course, depend on the length of the operating cycle, on variations in production rates, and so forth. The average concentration of vapor around a cleaning vat where parts, all of one type, are carried on a conveyer at a uniform rate might be determined satisfactorily from an hour or so of sampling whereas an operation of an intermittent nature and of varying workload might require a number of samples collected over a period of days or even weeks, and, in some cases, the collection of single samples for hours or even days.

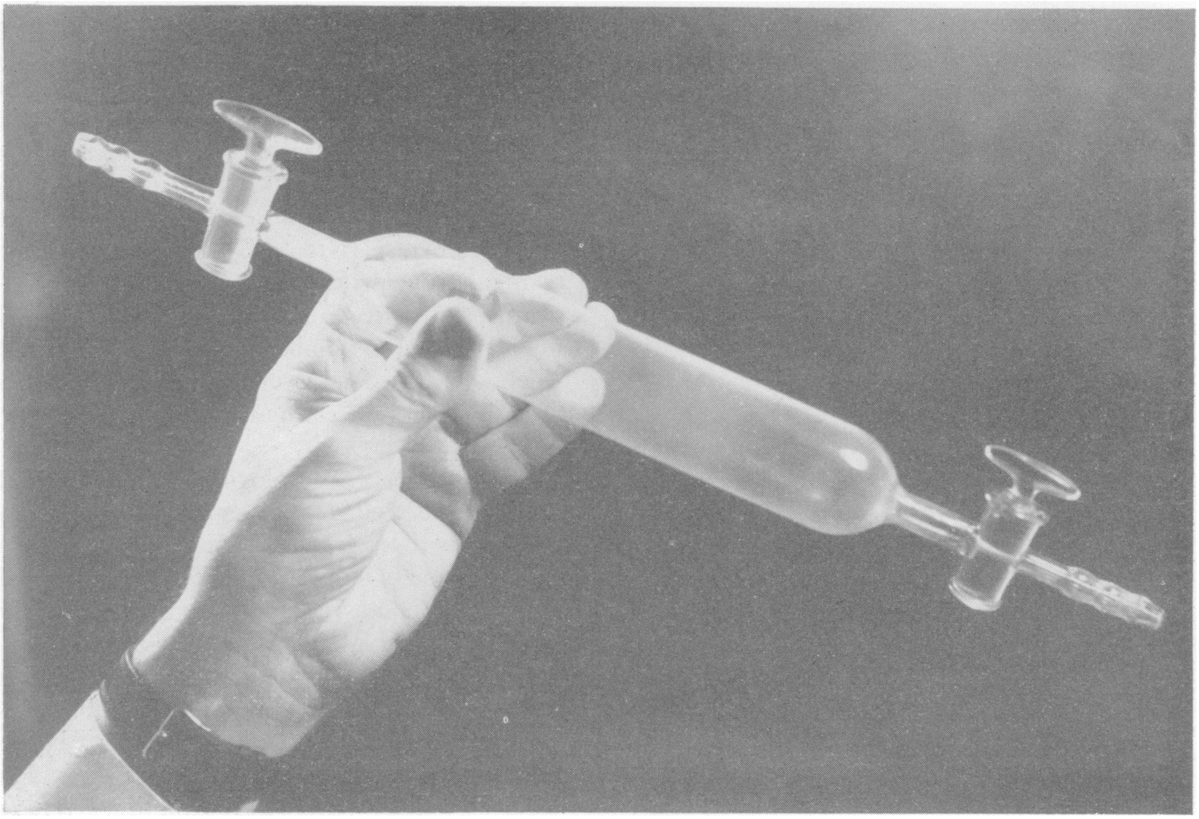
The time interval employed in the individual samples collected for measuring fluctuations in concentration depends on needs and also on the instruments employed. Some devices used for such purposes collect what are variously called "instantaneous," "snap," or "grab" samples. With these the volume of air sampled is small, ranging usually from a few cubic centimeters to the amount held by a small bottle or flask. Ordinarily, a few seconds or less is sufficient time to collect grab samples. Where large volumes of air must be sampled to get enough material to analyze, equipment designed for long-period sampling may be employed for the shortest time interval practical in the circumstances.

Ideally, a sampling technique should give an immediate answer. A number of instruments and methods which do give desired information instantaneously or within a few minutes have been developed, and the prospects are bright for more equipment of this type. At present, however, measurement of most airborne contaminants requires the collection of samples which must be returned to the laboratory where hours or even days of processing are required to yield the answers.

Types of Instruments

I will not attempt to describe in detail the many types of instruments used in air sampling. Generally, however, they have a source of suction to draw the air through some type of collecting or analyzing device and a means for measuring the volume of air sampled.

If a sample is to be collected continuously over a fairly long period to evaluate average con-



Gas sampling tube.

ditions, or if we wish to sample a relatively large volume of air, we would probably use a motor-driven pump. In atmospheres where the possibility of explosion must be considered, we would probably avoid using electrical equipment and use compressed air or hand-operated pumps instead. The sampling rates employed seldom exceed 2 or 3 cubic feet of air a minute and often are less than a tenth of such rates. Rotameters, pressure gauges, orifice meters, or other appropriate metering devices, may be used to measure the air flow.

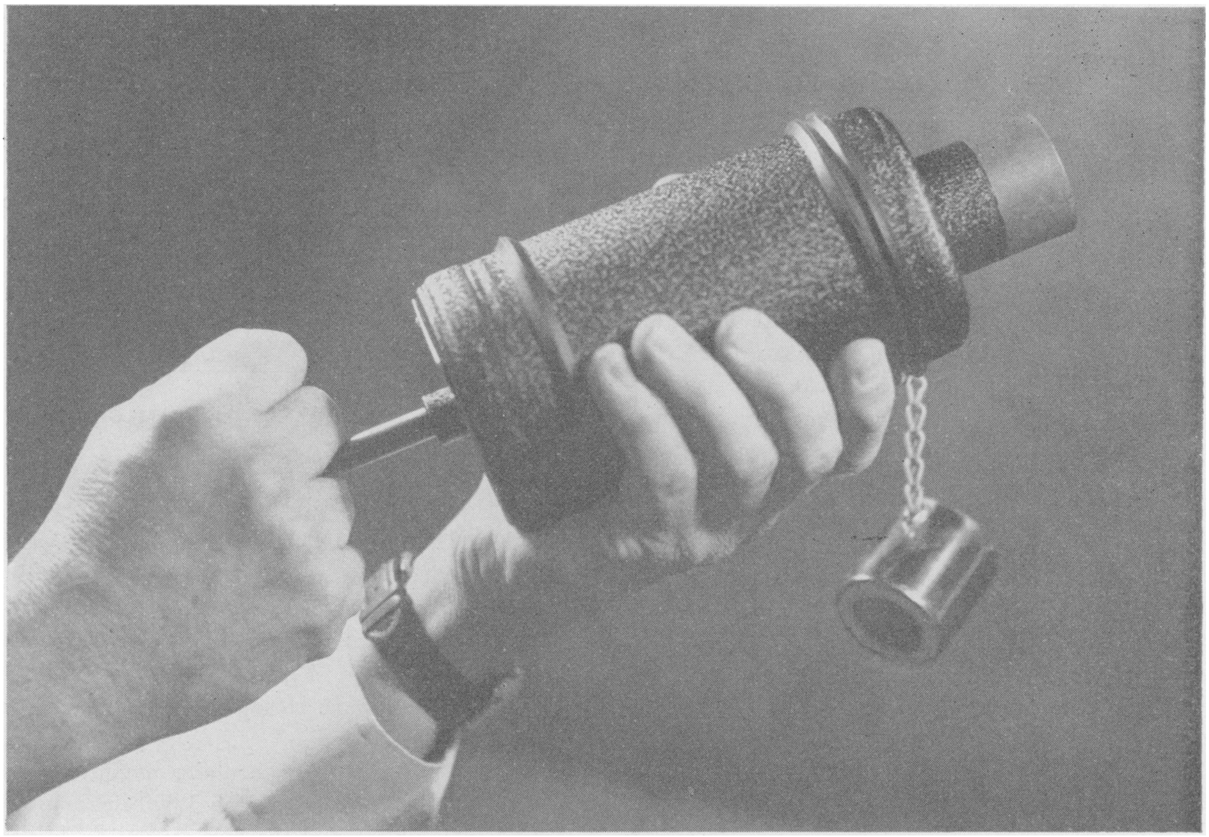
The collecting mechanisms employed are numerous because of the variety of contaminants. Particulate material, such as dust, might be collected on one of the many filtering materials in common use or might be picked up by an electrostatic or thermal precipitating device. Another common technique employs impingement. The choice of collector would depend also on whether the dust is to be weighed, counted, measured for size, or subjected to chemical analysis.

Gaseous matter might be absorbed by bubbling it through a suitable collecting liquid or by adsorbing it on such material as activated charcoal or silica gel.

Instantaneous or grab-type samples of gases might be collected in bottles or flasks which are first evacuated in the laboratory and then opened at the sampling point. Another technique is to displace the air in a double-inlet type of bottle, usually with a hand-operated pump or rubber aspirating bulb. A simple procedure is to fill the bottle with water; as the water drains out, it is replaced by the air to be sampled.

Sampling devices of various types are pictured in the accompanying photographs. They all have two features in common: small size and simplicity of operation.

As stated before, the preferred instrument is one which gives an on-the-spot answer. Among interesting instruments of this type are simple devices in which air is drawn by means of rubber aspirating bulbs through tubes of chemicals; the chemicals develop immediate color changes proportional to the amount of specific contaminants present. Tubes containing chemi-



Hand-operated pump for filter sampler.

cals are available for measuring carbon monoxide, hydrogen sulfide, hydrogen cyanide, and possibly other gases. Oxides of nitrogen may be measured in the field by collection in large hypodermic syringes and comparing with standards the color developed when suitable chemical reagents are added.

Other more complex devices for obtaining answers in the field utilize some physical characteristics of the contaminant in question. One group of instruments utilizes the principles of combustion. For example, vapors that are combustible may be burned on a heated platinum wire in a balanced electrical circuit. The vapors, in burning, raise the temperature of the wire, increasing its resistance, and the change is measured with a galvanometer. Since such instruments are not specific, it is necessary to calibrate the instrument for the particular contaminant.

Certain substances such as the vapors of mercury and of some chlorinated hydrocarbons will prevent the transmission of ultraviolet light. This property is utilized in some instruments by measuring the amount of ultraviolet absorption. The measurement is indicated on a dial.

Some instruments indicate the number of dust particles in the air. These devices are usually based on a measurement of the amount of light scattered by the dust. Even though they have certain defects, they are useful in determinations of dust of uniform particle size.

Recording devices are being employed with increasing frequency to provide a permanent record of the air conditions measured continuously at a specific location. When attached to suitable instruments, recorders show the fluctuations in concentration which take place and, when compared with concurrent work records, often indicate where control measures or changes in operating methods are advisable. Recorders operate on various principles, for example, changes in electrical conductivity produced by absorption of such gases as sulfur dioxide.

Maximum and Specific Limits

Before concluding, I should like to return to the subject of limits since air sampling to determine health hazards usually requires a decision by authorities that a hazard is or is not present, and, should it be present, they must also decide how serious it may be.

For many years there have been figures known as M.A.C. values with M.A.C. standing for "maximum allowable concentration." The expression has often been a center of controversy because of differing viewpoints concerning interpretation of the values. In jurisdictions where lists of M.A.C. values are part of legal regulations, some administrators have operated on the basis that any sample showing an M.A.C. to be exceeded is a violation. Similarly, I suppose, so long as the M.A.C. is not exceeded, the interpretation would be that no problem exists.

Actually, of course, the question is not so simple. As I stated earlier, although we now have fairly satisfactory toxicological information about a number of substances, the limits in common use do not necessarily represent similar degrees of hazard. Some limits are established to prevent serious injury or possible death. Others are to prevent concentrations that would be irritating to breathe, though not necessarily dangerous. Still others are to prevent levels of odor that are disagreeable. The degree to which people can tolerate or to which they are at all disturbed by such conditions varies greatly, and it is not possible to determine exactly how much of their disturbance is psychological rather than physiological, nor is it correct to dismiss the psychological condition or effect as unimportant.

Most people experienced in industrial hygiene are aware that M.A.C. values for different substances have different origins and represent different degrees of hazard. Because of this, there has been a search for many years for a better expression than "maximum allowable concentration." "Threshold limit value" is one such term. It implies something possibly less legalistic since more than one type of threshold might be indicated whereas "allowable" presents an inflexible aspect. "Hygienic standards" is another proposed term. None of the proposed expressions has won complete acceptance, and, consequently, "M.A.C." is still heard wherever industrial hygienists gather, possibly because of our fondness for initials. A recent movement has considerable backing to use the same initials but to substitute "acceptable" for "allowable."

"Maximum acceptable concentration" would seem to have a good chance for widespread use because it indicates a standard in which the degree of hazard has been given some considera-

Encyclopedia of Industrial Hygiene Instruments

The University of Michigan Institute of Industrial Health and School of Public Health and the Public Health Service Occupational Health Program, Cincinnati, cooperated in the preparation of the Encyclopedia of Instrumentation for Industrial Hygiene. Technical editors are Charles D. Yaffe, Dohrman H. Byers, and Andrew D. Hosey of the Public Health Service.

The 1,243-page volume contains comprehensive information on the approximately 1,000 air-sampling instruments exhibited at the Symposium on Instrumentation for Industrial Hygiene, held at the university, May 24–27, 1954. It also contains 28 technical papers presented at the symposium.

Described are instruments for measuring air velocity and metering air, laboratory-type instruments of specific application to industrial hygiene, instruments specifically designed for atmospheric pollution evaluation and meteorological measurements, instruments for sampling and analyzing air for contaminants in industrial environments, and instruments for measuring sound and vibration, for measuring ionizing radiation, and for measuring ultraviolet, visible, and infrared energy.

Included for each instrument are a physical description, data on performance, and information on uses, operating principle, source, and price. In addition, there are photographs, wiring and schematic diagrams, and operating, calibrating, and maintenance instructions.

The encyclopedia was published by the university in April 1956 and may be ordered from the Publications Distribution Service, University of Michigan, Ann Arbor, Mich.

tion. If so, it might be well to point out that future use of M.A.C. will need to be accompanied with a definition of the intended meaning.

In conclusion I refer those interested to the following discussion of this point taken from "A Guide to Uniform Industrial Hygiene Codes or Regulations," which was issued a few years ago by the American Conference of Governmental Industrial Hygienists.

"Maximum concentrations shall not be used as the sole criterion for establishing evidence of hazard to health or well-being, but the evaluation of a possible hazard shall also be subject to other pertinent factors such as the nature of the contaminant and the frequency and duration of the exposure or clinical evidence of harmful effects.

"Thousands of elements, compounds, and mixtures are employed or encountered in places of employment, and the number of new ones being utilized is constantly increasing. Some of these have been found to injure health if present in the working atmosphere in excessive concentrations. Others, while not producing demonstrable injury, have been found to cause irritation, coughing, sneezing, objectionable breath, or other undesirable results.

"Through actual experience in industry, a great deal has been learned about the effects of some substances. This information has been supplemented by considerable laboratory research. The body of knowledge regarding toxicity of substances is fairly large and is steadily increasing in size. Much more remains to be learned, however, not only about the newer materials but also about some which have been studied for many years. Honest differences of opinion as to the safe concentrations of some of the more common toxic materials exist among authorities in the field of industrial toxicology. Greater differences of opinion are naturally encountered with respect to the limits to recommend for substances on which there is more limited experience.

"Despite the gaps in our present state of knowledge, specific figures must of necessity be provided at least as a guide toward the definition of what constitutes a safe working atmosphere. Specific figures are desirable not only for the use of the authority in determining essential compliance with codal provisions but also are helpful to industry as benchmarks upon which it can base a design of control equipment which it plans to install. There are some who feel that specific figures should not be included unless there is a great deal of conclusive evidence to justify the figure established. However, if no figure is given for a substance because of the absence of positive proof, when question arises as to the presence of a suspected hazard, the authority must render a decision regardless of whether or not a specific value is contained in the code. Consequently, it is felt advantageous to make the list in the code as inclusive as is possible."

PHS Announcement

Dr. Theodore J. Bauer, formerly chief of the Public Health Service Communicable Disease Center in Atlanta, has been named deputy chief of the Bureau of States Services. He succeeds Dr. Leroy E. Burney, recently appointed Surgeon General of the Service.

With the Public Health Service since 1934, Dr. Bauer has served as venereal disease control officer for the Chicago Board of Health during 1942–48, and as chief of the Venereal Disease Division during 1948–53, when he was appointed to the Communicable Disease Center post.

He is a graduate of the University of Iowa liberal arts and medical schools.