An Ionization Anemometer

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By J. E. LOVELOCK and E. M. WASILEWSKA, Medical Research Council, Group for Research in Industrial Physiology, Harvard Hospital, Salisbury, Wiltshire

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ABSTRACT. An anemometer is described for the measurement of air movement in the region 0–300 ft./min. The instrument is omnidirectional, rapid in response and equally sensitive over the whole range of velocities covered. A unidirectional anemometer and a flowmeter working on the same principle are also described.

INTRODUCTION

In that branch of applied physiology dealing with the effects of the thermal environment there exists a strong need for an anemometer capable of measuring with convenience and accuracy air movements as slow as 10 ft./min. Of the instruments at present available to the physiologist, namely the katathermometer, vane anemometers and the hot-wire anemometer, none is entirely satisfactory. The katathermometer is very slow in response and of uncertain accuracy and the vane anemometers are highly directional and not sufficiently sensitive. The hot-wire anemometer, although satisfactory from most points of view, suffers the disadvantage of varying sensitivity with wind direction. This paper describes an anemometer which is omnidirectional, rapid in response and sensitive to wind velocities of below 10 ft./min.

GENERAL PRINCIPLES OF OPERATION

The mobility of ions in air in fields of moderate electric intensity is sufficiently slow for their paths to be strongly affected by slight air movement. The transport of ions in air can easily be measured in terms of an electric current and the effect of air movement upon their transport measured as a change in value of that current. The simplest form of anemometer based on this principle is illustrated in Fig. 1. It consists of two parallel metal plates P_1, P_2, enclosing a volume of air ionized by irradiation with α-particles. The plates are connected in series with a battery and a meter. If the battery potential is greater than about 100 V. the current passing between the plates in still air is that due to the collection of almost all the ions. When the air moves in the plane parallel to that of the plates some of the ions are blown away or, alternatively, are made to take longer paths so that they are offered a greater chance of recombination and neutralization of their charges, both of these occurrences resulting in a decrease in the current passing through the meter. The sensitivity of the parallel-plate anemometer varies with the distance separating the plates and is inversely related to the area of the plates and to the intensity of the electric field between them. In general, the longer the ions take to reach a collecting plate, whether on account of lessened velocity or of increased distance, the greater the effect of a given air speed. In practice no difficulty is found in obtaining adequate sensitivity with convenient dimensions and potentials. For example, with an anemometer constructed as shown in Fig. 1, with plates 5 cm. apart, 5 cm. in diameter, and with a p.d. of 120 V., it was possible to measure wind velocities of less than 10 ft./min.

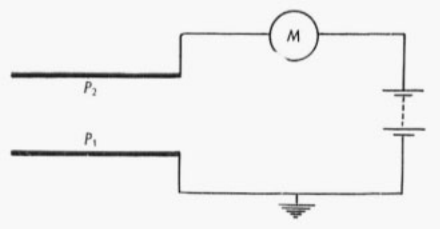


Fig. 1. Parallel-plate model of anemometer: P_1 circular plate coated with emitter; P_2 circular collecting plate electrode

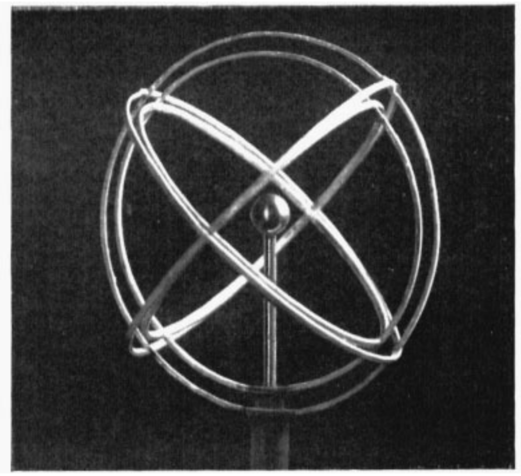


Fig. 2. Omnidirectional model of anemometer

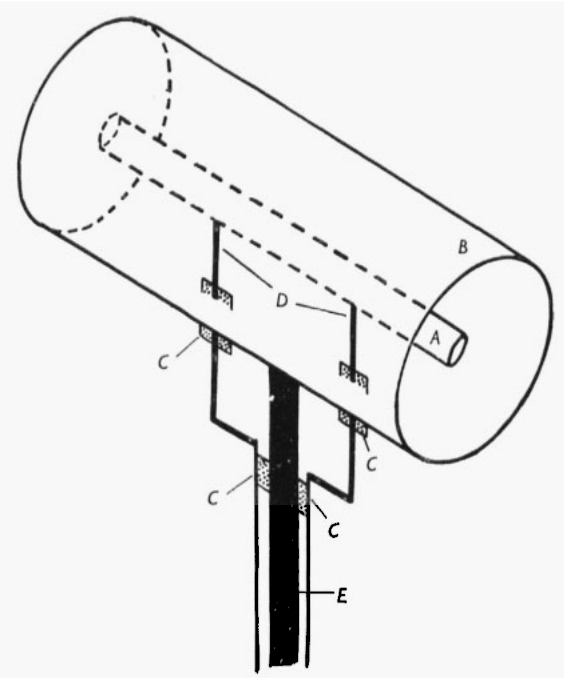


Fig. 3. Gas flowmeter: *A*, cylindrical collecting electrode; *B*, tube with inner surface coated with emitter; *C*, polythene insulation; *D*, leads to collecting electrode; *E*, lead to emitter

The simple instrument just described has the disadvantage of indicating air movement in one plane only and is insensitive to wind perpendicular to that plane. The anemometer illustrated in Fig. 2 is, however, equally sensitive to winds from all directions. It consists of two concentric spherical openwork cages, each with a small spherical electrode coated with

an α-particle-emitting element at its centre. The outer cage acts as an earthed screen, the inner cage is connected through a meter to earth and the central sphere to a source of positive potential of about 120 V. As in the parallel-plate model any air movement across the cage prevents some of the ions from reaching the collecting electrode, the inner cage, when the meter indicates a decreased current. On the principle of ion convection it is also possible to make gas flowmeters which have great sensitivity and offer practically no resistance to gas flow. The construction of such an instrument is illustrated in Fig. 3. It consists of a metal tube coated on the inside with α-particle-emitting material and connected to a positive potential. Within the tube, and concentric with it, is a cylindrical collecting electrode which is connected through a resistance to the meter as with the collecting electrodes of the other anemometers.

Temperature and humidity effects

The range of α-particles and the mobility of ions in air are dependent upon the temperature, pressure and relative humidity of the air, but the magnitude of these effects upon the calibration of the instruments can be minimized by the following arrangements. If the volume of air enclosed between the electrodes is such that it includes the maximum range of all the α-particles emitted, then changes in the range of the α-particles will not alter the total number of ions produced within the enclosed volume and consequently will not affect the current passing through the meter. The mobility of positive ions, unlike that of negative ions, is only slightly affected by changes in relative humidity or by the presence of traces of foreign gases. If the collecting electrode connected to the meter is made the negative electrode, the ion current measured will be that due to the positive ions only and will be unaffected by humidity. Allowance must be made for the remaining variations in mobility of the positive ions with temperature and pressure in precise measurements of air velocity or in compensating circuits introduced in the meter.

Constructional details

The first problem affecting the practical design of an ion anemometer is the choice and quantity of radio-active element needed. The choice is limited to an α-particle-emitting element, since the ionization of air by β- and γ-radiation in the small volume of the anemometer is far too small to be of practical use. Of the naturally occurring α-particle-radiating elements the following only are suitable: ionium, radium, polonium and radio-thorium. Radium D and mesothorium I which have been allowed to grow an equilibrium quantity of polonium and radio-thorium respectively are also suitable. The other naturally occurring radio-active elements are either insufficiently active or have half-lives too short for convenient use. The synthetic α-particle-emitters, neptunium, plutonium, americurium and curium, would be eminently suitable if they were commercially available at prices competitive with those of the natural radio-active elements. In all of the anemometers described in this paper polonium has been used as a source of α-particles. In spite of its rather short half-life of 136 days, requiring a replacement of the source at 6-month intervals, polonium has distinct advantages over the other radio-active elements. It is cheap, it can be electroplated on to silver-plated metal objects and, since it emits α-particles with a range of only 4 cm. in air, relatively large quantities can be used without fear of radiation hazards such as would arise with an element emitting β- and γ-radiation in addition to α-particles. The quantity found necessary to obtain an ion current large enough for convenient measurement with simple electro-meters, and free from random fluctuations, is between 50 and 250 μc.

The detailed construction of the omnidirectional model is illustrated in Fig. 2. The central sphere was made of silver-plated brass uniformly coated with 250 μc. of polonium. It was 1 cm. in diameter and supported on a stalk 3 mm. in diameter. This sphere was surrounded by two concentric wire grids, each of which was made by joining three identical metal rings in such a way that all points of contact were at right angles. The obstruction to air flow due to these grids was, as Fig. 2 shows, small. The two outer grids were made of brass turned from a cylindrical block and silver-plated. The internal diameter of the inner grid was 8 cm. and that of the outer 9 cm. The two grids and the central sphere were attached to two concentric brass tubes and a concentric brass rod respectively. These were insulated from each other by polythene sleeving since, in view of the high input resistance (100 MΩ) in the measuring circuit, insulation with polythene or similar material was essential. The system of concentric tubes and rods formed a 'jack' type of plug which fitted a socket attached to the lead from the meter. The construction of the tube type of anemometer or flowmeter is shown in Fig. 3. It consisted of an aluminium tube, 6·3 cm. long and 3·2 cm. internal diameter, and containing an inner lining of silver foil coated with 125 μc. of polonium. The ion-collecting electrode was a plated brass rod, 5·5 cm. long and 0·6 cm. diameter, situated concentrically in the tube, both tube and rod being connected to a plug similar in every respect to that attached to the cage type of anemometer.

Amplification circuit

The quantity of radio-active material used in the anemometers is sufficient to provide ionization currents of about 10^{-8} A. Currents of this order can be amplified to provide direct readings on a conventional moving-coil meter by the use of a simple one-stage circuit. This has been made possible

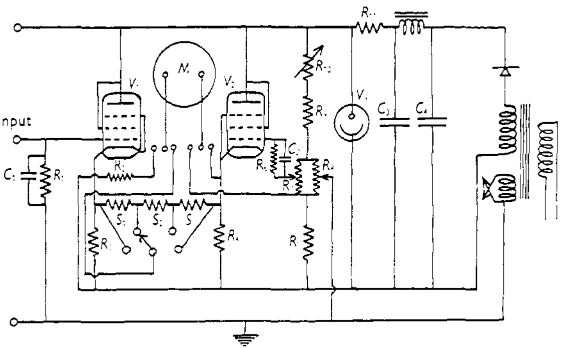


Fig. 4. Circuit diagram of anemometer amplifier: V_1, V_2, type E.F. 37 valve; V_3, type V.R. 105 valve; M, meter 0–100 μA.; C_1, C_2, 300 pF.; C_3, 8 μF.; C_4, 4 μF.; S_1, S_2, S_3, shunt resistances; L_1, 50 H; R_1, R_6, 100 MΩ; R_2, 100 kΩ; R_3, R_4, R_{11}, 10 kΩ; R_5, 3 kΩ; R_7, R_8, 2 kΩ; R_9, 25 kΩ; R_{10}, 5 kΩ

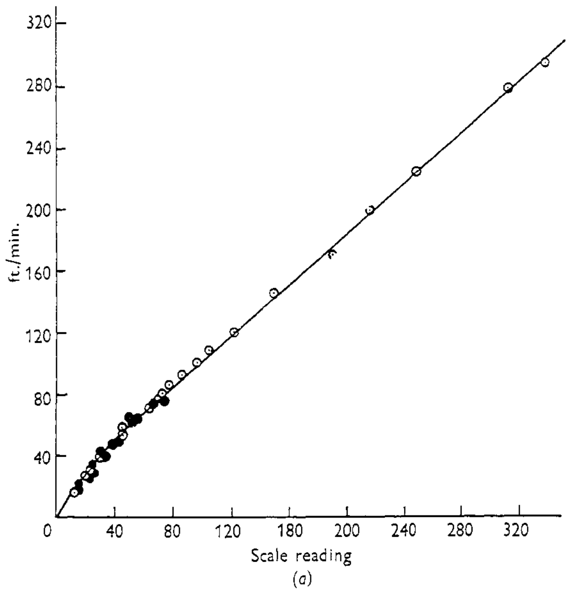
by the discovery of Thorp* that valves of types E.F. 36 and E.F. 37 have a sufficiently low grid current to operate in circuits having input resistances as high as 10^8 to 10^9 Ω. The simplest circuit would be a single E.F. 37 valve with a grid resistance of 100 MΩ, a 100 μA. meter in the anode lead and a 'backing off' current supplied to the meter to give a zero reading for still air conditions. Although desirably simple, this type of circuit has the disadvantage of a considerable zero

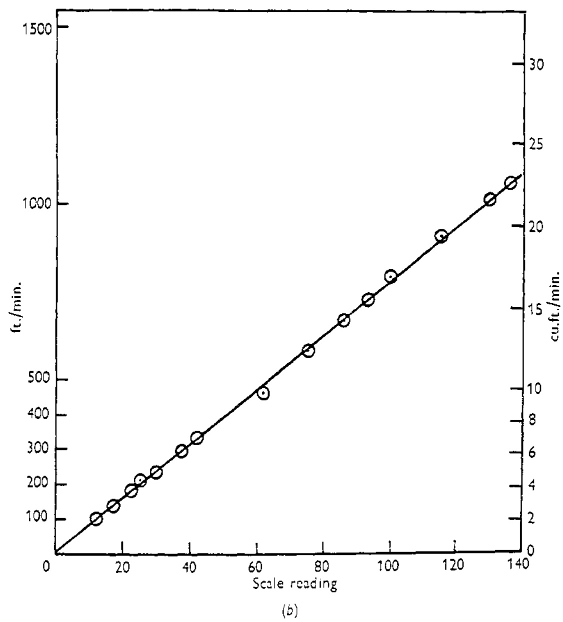
* Thorp, R. M. *Elect. Engng, N.Y.*, **17**, p. 67 (1945).

drift, which would be most troublesome if used in connexion with the ion anemometers. Accordingly, a balance circuit using two E.F. 37 valves arranged as shown in Fig. 4 was made. By virtue of the voltage-stabilizer valve and the balanced circuit, the meter reading and sensitivity gave no perceptible change with supply voltages between 190 and 250 V. The additional complication of this circuit, using two valves in a balance bridge, is more than compensated by its great stability as compared with the conventional single-valve amplifier. From 5 min. after switching-on zero drift was less than 2 μA. in 1 hr. The rapidity of response is governed principally by the values of the grid-input resistance and condenser. The amplifier shown in Fig. 4 has a grid resistance of 100 MΩ and condenser of 300 pF. which values give an 0·03 sec. time-constant at which the meter shows rapid fluctuations when measuring ambient air movements. The evaluation of the extent of these fluctuations may be useful in assessing the turbulence of the air, but for convenience it was often found useful to use a larger value of grid condenser to average the wind velocity over a time period of about 0·5 sec. By means of switched shunts the microammeter was arranged to measure 0–100, 0–300 and 0–1000 μA., and, by adjustment of the grid and cathode resistances of the amplifier, these shunt positions were made to correspond approximately to 0–100 and 0–300 ft./min. with the cage-type anemometer. When polonium is used as a source of α-particles it is periodically necessary to adjust these resistances to allow for the decrease in activity of the source due to its somewhat rapid decay. To facilitate observations, the meter was connected in such a way as to indicate an increase in velocity by an increase in reading.

Calibration and testing

The anemometers were calibrated in low-velocity, non-turbulent wind tunnels at this laboratory and at the N.P.L. The calibrations were checked by simultaneous measurements with shielded hot-wire anemometers designed and constructed by the Physics section of the N.P.L. and results are shown in Fig. 5. It can be seen that the results of the various tests are in close agreement and that the calibration of the ion anemometer was consistent. The relationship between wind velocity and meter reading with both the tube and cage-





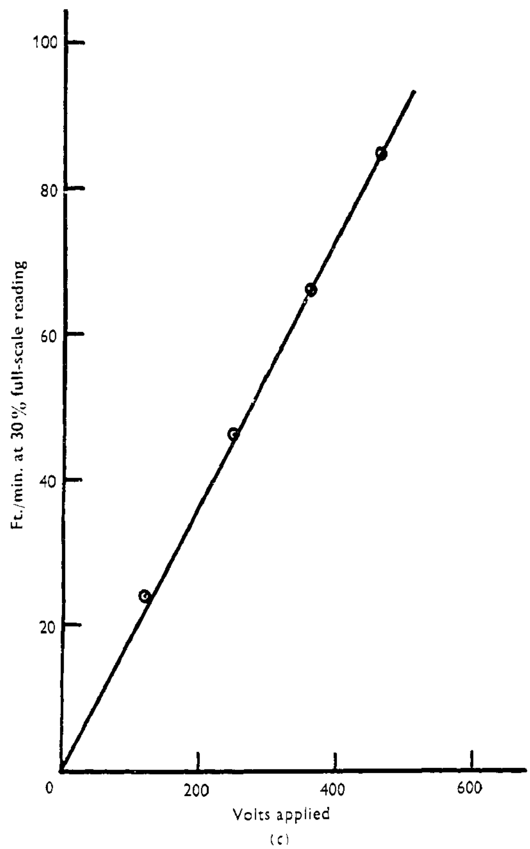


Fig. 5. Calibration curves: (*a*) omnidirectional model of anemometer; (*b*) flowmeter; (*c*) variation of sensitivity with applied voltage (omnidirectional model)

type anemometers was very nearly linear over the range 0–1000 and 0–300 ft./min. respectively. With both instruments there was an increasing curvature in the relationship between wind velocity and scale reading, when more than 30 % of the ions were prevented from reaching the collecting electrode. In practice it is undesirable to carry measurements beyond this value owing to the marked decrease in precision that occurs. The behaviour to winds from various directions of the omnidirectional instrument was tested by rotating the anemometer in a wind tunnel while keeping the air velocity constant. Fig. 6 shows the results of this test. The variations in sensitivity with wind direction were less than ±4 % and further experiments showed that these variations were due largely to non-uniformity of the polonium coating on the central sphere. Throughout all the tests above described the potential across the cage was maintained at 105 V. The sensitivity of the instrument can, however, be conveniently varied by altering this voltage. The sensitivity varies linearly and inversely with voltage over the range 100 to 500 V.

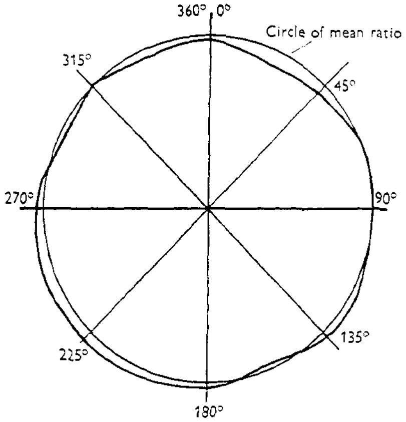


Fig. 6. Variation of sensitivity with wind direction in a horizontal plane for the omnidirectional anemometer

The effects of temperature and pressure on the calibration of the instrument are shown in Fig. 7. With an ambient relative humidity of 50 % a change of sensitivity of ±1 % occurred with a relative humidity change of ±40 %, the greater sensitivity occurring with lower humidity. Within the range of air conditions normally encountered in occupied rooms the changes in sensitivity due to variations in these quantities can be seen to be slight. By suitable modification of the electrode assembly, instruments highly sensitive to air-pressure variations can be made. Such instruments are available commercially and have been described by Downing and Mellen.* An opportunity of testing the use of the anemometer under severe field conditions was provided during the recent Arctic cruise of H.M.S. *Vengeance*. Measurements of the ambient air movement on the mess decks of this ship under widely varying external weather conditions were made and will be reported elsewhere. The instrument was found to be convenient and simple to use. Recalibration on its return showed no change in sensitivity as a result of the severe conditions and rough handling inevitable in such investigations.

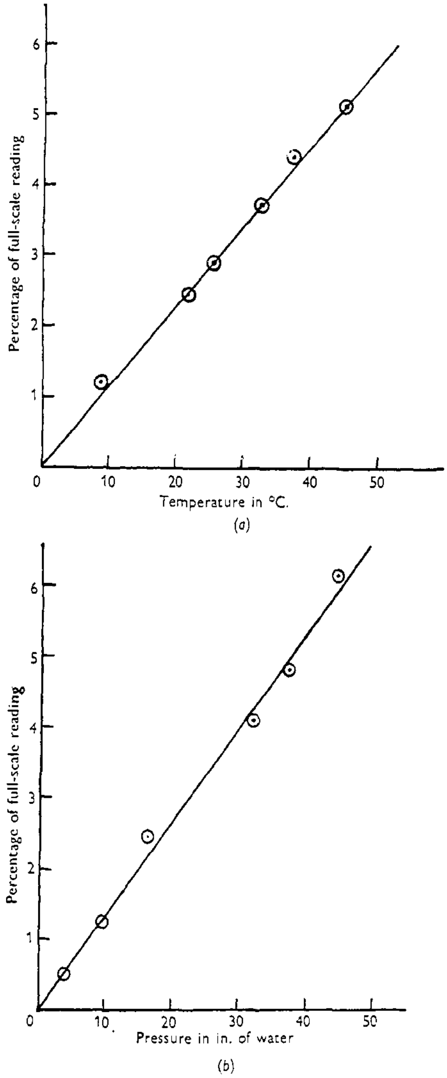


Fig. 7. Temperature and pressure effects: (*a*) variation of sensitivity with temperature measured in °C.; (*b*) variation of sensitivity with pressure measured in inches of water

ACKNOWLEDGEMENTS

We wish to acknowledge our gratitude to the staff of the Physics section of the N.P.L. for their advice and help in the calibrations of the anemometer. Also we are indebted to Mr R. Canaway of Harvard Hospital, who constructed all the apparatus described in this paper.

* Downing, J. R. and Mellen, G. *Rev. Sci. Instrum.* **17**, p. 218 (1946).

ERRATUM

In the paper by E. R. Cooper and M. C. Probine on *Measurement of Radiation Falling on a Flat Surface*, published in our October 1949 issue (p. 349—l.h. column, 5 lines from bottom), 'light scattered by *C*' should read 'light scattered by *B*'.