A Portable, Photo-Recording Aitken Counter

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ABSTRACT

A modern replica of the Aitken counter for detection of aerosol particles smaller in diameter than a half wavelength of visible light has been constructed using modern materials. The instrument employs photographic recording, rather than visual observations, of the cloud drops formed on these particles. This feature eliminates observer bias and provides a permanent record of the observation. Comparison of this instrument with a Pollak photoelectric nucleus counter indicated correspondence in the concentration sensed to well within experimental sampling error.

1. Introduction

The particulate fraction of the atmospheric aerosol can be measured by several techniques. Particles of 1 μm or greater diameter have significant mass, and may be inertially separated for subsequent gravimetric, chemical or microscopic analysis; those of greater than 0.3 μm diameter can be detected by light scattering techniques; and an additional downward extension in detectable size can be obtained by measuring the charges carried by the particles.

Particles of radius $<3\times 10^{-6}$ cm have little mass, do not scatter light and according to Rich *et al.* (1959), have less than a 50% probability of carrying a charge. These particles are relatively important meteorologically because they act as "sinks" for small ions, reducing atmospheric conductivity (Wait, 1946), and as the precursors of particles in the size ranges which act as cloud condensation nuclei (Lee and Jiusto, 1974; Hogan, 1976) or radiation scatterers. The relative importance of these smaller particles justifies the exploitation of more difficult detection techniques, but these techniques must be compatible with field and maritime environments.

Quoting Aitken (1923), "different ideas suggest themselves . . . but they all depend on supersaturating the air . . . in which they are suspended, and making each particle grow into an easily detectable drop." These drops were initially detected by allowing them to precipitate, and actually counting them, in the manner of Aitken (1923) and Sholz (1932); another technique estimates the initial aerosol concentration as a function of the opacity of the fog formed, as originally applied by Coulier (1879), automated by Bradbury and Meuron (1938), and brought to a fine art by Pollak and Morgan (1940) and Pollak's many subsequent collaborators.

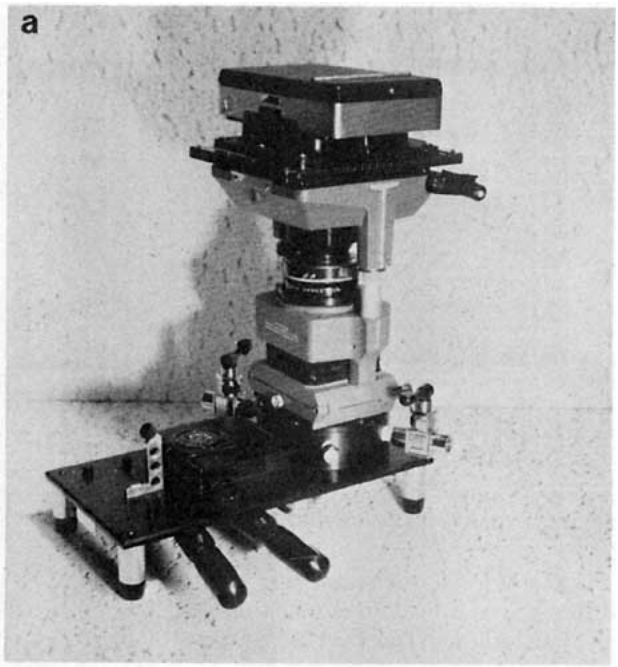
Aitken's technique has certain advantages. An Aitken counter is, in theory, an "absolute" particle detector which derives its calibration from purely geometric considerations and requires no comparison with other instruments or standards. Additionally, many historic determinations of aerosol concentration by Aitken (1923) and those reported by Landsberg (1938) were obtained with this type counter, increasing the value of measurements with a similar instrument today, even if a superior instrument were available.

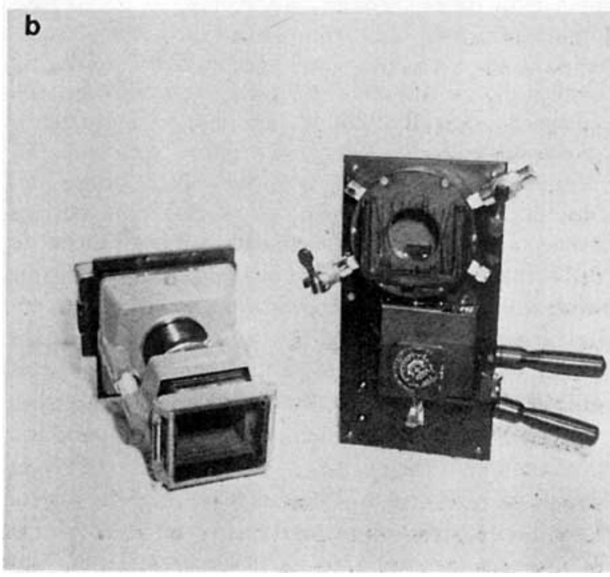
Interest in detecting the presence or absence of a secular change in aerosol concentrations over the seas and in determining the total aerosol concentration over the polar caps required the construction of a modern replica of Aitken's counter to ensure that modern aerosol measurements were comparable to historic measurements found in the literature. Two of these counters have been constructed to date. One has been used at this laboratory as a reference instrument for calibrating photoelectric counters, and in the field in Hawaii and Greenland. An identical instrument has recently been completed for similar use by NOAA in the Geophysical Monitoring for Climatic Change Program.

2. Description of instrument

The original Aitken counter had the geometric form of a short cylinder, about 5 cm in diameter by 1 cm in height. This cylinder was internally covered by moist blotting paper, except for the glass centers of the flat ends. The lower surface served as a counting stage and the upper as a window through which to view the stage with a small magnifier. A small inlet valve was located at one side of the cylinder, and an exhaust valve opposite. A small piston pump was connected at right angles to the cylindrical cloud chamber. This pump was used to aspirate the chamber and then, on closing the inlet, to create the supersaturation, making a fast expansion by extending the piston. The drops were counted in dark field illumination after precipitating to the lower stage. Aitken's accounts of his development of this and his subsequent "pocket" counter are very revealing of practical problems in aerosol physics.

The photographic Aitken counter (shown in Figs. 1) is a geometrically similar short cylinder of slightly more than 10 cm diameter by 3 cm high, attached by a short tube to an expansion piston, providing the Aitken expansion of ratio of 1.21. The major deviation from the original Aitken technique is that, rather than counting the droplets after they fall to the lower stage, they are photographed while still suspended. This allows the lower surface to be entirely humidified but, more important, reduces operator error, as the drop records are preserved on film for recounting.





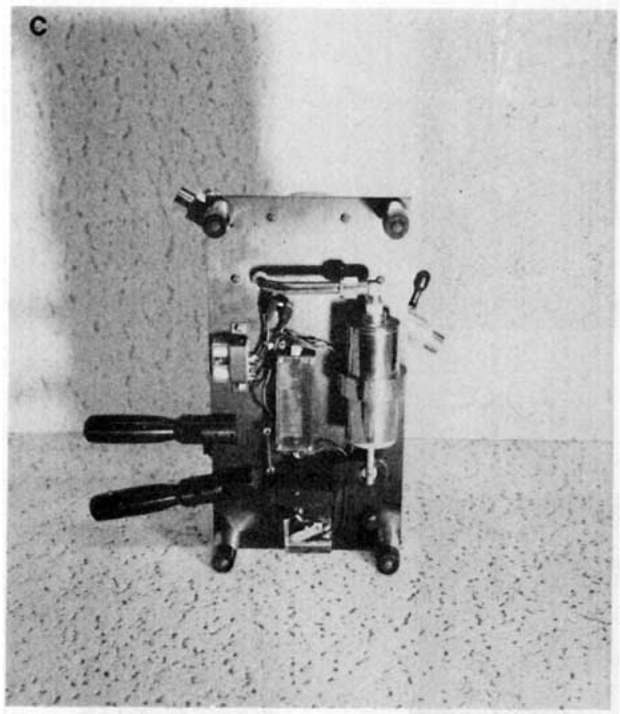


FIG. 1. The photo recording Aitken counter (a) shown assembled, (b) with camera removed to show the viewing window and collimator, and (c) a bottom view showing the expansion cylinder, linkage and time delay circuitry. The expansion ratio is fixed mechanically by the length of the piston stroke; an incomplete stroke will not fire the photo strobe.

A small window is required on the side of the cylinder to admit the light from a commercial photographic strobe light. A slit collimator of 1 mm width extends from this window to near the center of the cloud chamber. A fixed-focus lens and camera assembly is mounted at right angles to the collimator along the central axis of the cylindrical cloud chamber. This camera assembly is aligned by inserting a small metal target in the illuminated field, adjusting the film plane to target distance for sharp focus, and then locking the assembly in place. As only drops illuminated by the narrow beam from the collimator are photographed, there is no necessity to judge if a drop is in focus; all drops are counted. The fixed-focus lens was initially regulated at an object/image ratio of unity; thus no calibration of angular magnification is required.

3. Method of operation

Aerosol-laden air is introduced through the inlet valve and exhausted using an accessory pump of about

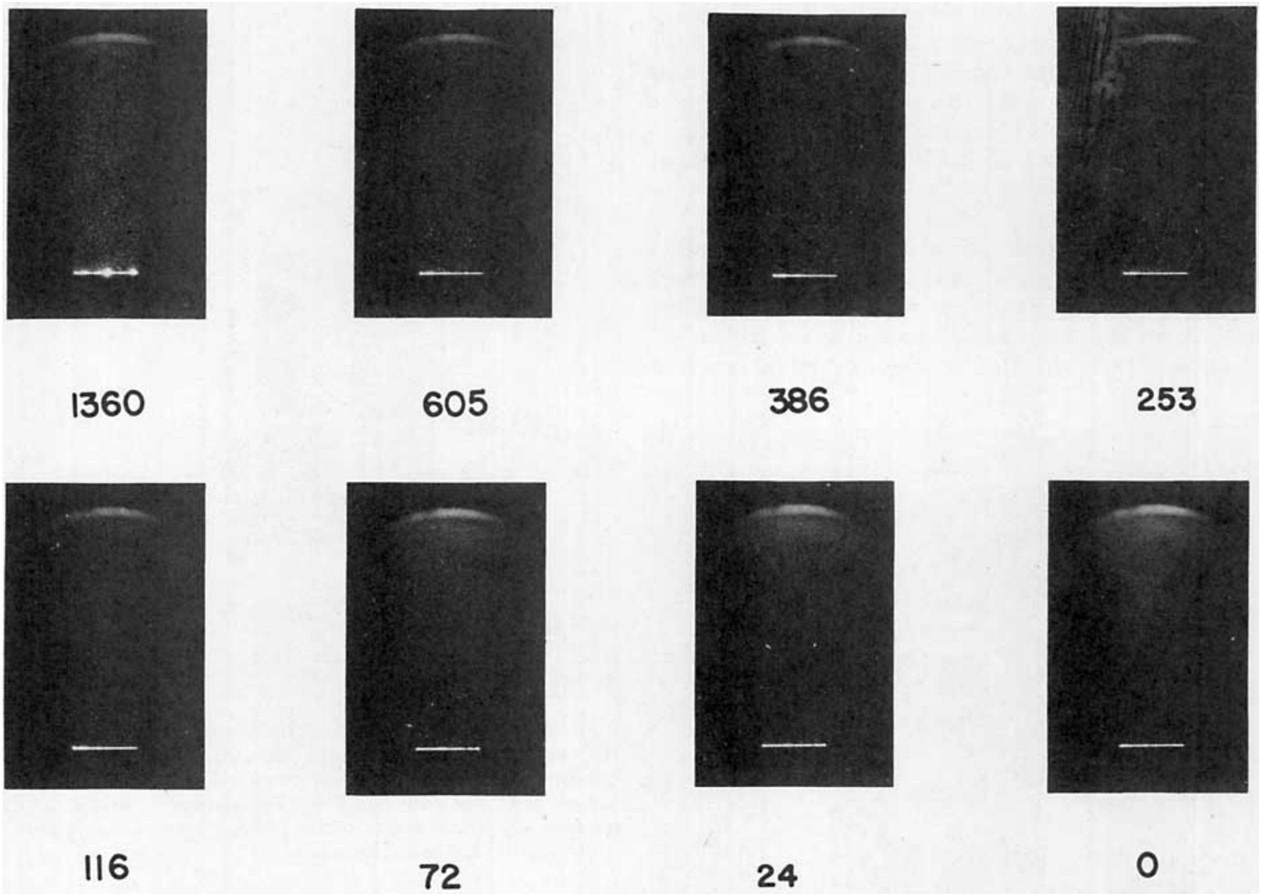


FIG. 2. Eight cloud chamber photographs showing the droplets formed on several concentrations of aerosol particles as indicated by repetitive Pollak concentration determinations.

2.0 ℓ min^{-1} capacity. The expansion pump is slowly cycled during this period to ensure it is also flushed. The pump is stopped and the inlet and exhaust valve sealed. A few seconds are allowed for the system to come to rest and equilibrium and to open the camera shutter. The expansion is created by squeezing the two handles which, in turn, withdraws the piston. There is considerable mechanical gain in the system allowing a rapid rate of expansion. Upon reaching the limit of its travel, the piston closes a switch initiating the cycle of a time delay relay. After a droplet growth period of 1.2 s, the time delay relay switches, flashing the strobe light and illuminating the droplets to be recorded. The shutter is then closed.

The expansion sequence can be repeated several times on the same film frame when a stable aerosol of low concentration is being measured to reduce random counting error. The film is then processed, the number of droplets per square centimeter on the film determined, and this number multiplied by a geometric constant to obtain the drop concentration. This constant will vary with the exact collimator width and beam divergence of each instrument, but is approximately 12 times the number of drops per square centimeter, when a 0.1 cm collimator slit and an expansion of 1.21× are used. No correction for uncertainties reported by Jaenicke and Kanter (1976) due to inertial lag of growing drops has been applied, as none had been applied by Aitken, Nolan and Pollak, or Pollak and Metnieks, in their use of similar counters. Such corrections can be taken into consideration when thoroughly established, as the geometry of the system and the expansion are rigidly fixed. Typical droplet photographs are shown in Fig. 2.

An inherent uncertainty is present, in the design and construction of all Aitken or condensation nucleus counters, relative to the supersaturation produced in the counter, the repeatability of the production of this supersaturation, and consequently, of the minimum size of particle detectable by the counter. There are several techniques for calculating the critical supersaturation required for the growth of soluble particles, pure water drops and insoluble but wettable particles, as a function of the particle's radius. These techniques have been reviewed by Mason (1971) who presents a table showing the supersaturation required for growth of insoluble but wettable particles. Das Gupta and

TABLE 1. Minimum detectable particle size in Aitken counters. Initial condition: $T_0=289.16$ K, mixing ratio $w=11.4$ g kg^{-1}.

Pressure ratio P/P_0	Temperature T_F (K)	Mixing ratio w (g kg^{-1})	Super-saturation S (%)	Minimum radius (cm)
0.826	273.82	4.0	2.85	1.04×10^{-7}
0.847	275.79	4.65	2.45	1.22×10^{-7}
0.870	277.83	5.35	2.13	1.44×10^{-7}
0.893	279.94	6.15	1.85	1.77×10^{-7}

Ghosh (1946) present a very simple formula

$$S=\exp[(1.09\times10^{-7})(r^{-1})],$$

where S is supersaturation and r is particle radius (cm); this formula reproduces Mason's tabulation with a difference of less than 10%. The expansion produced in this counter is fairly rapid and is assumed to be adiabatic in the central portion of the chamber where the drops are photographed, allowing application of the dry adiabatic expansion formula

$$T_F=T_0(P/P_0)^{0.286}$$

to calculate the temperature drop in the chamber. The supersaturation produced as a result of this temperature change can then be calculated from the ratio of saturation mixing ratios at these temperatures. Assuming an initial temperature T_0 of 16°C (289.16 K), the supersaturation produced at several expansion ratios and the corresponding minimum particle radii detectable are shown in Table 1.

Examining the table, one finds that a very large change in the expansion ratio, i.e., about one-third of the length of the piston stroke, would only cause a change in the minimum detectable radius from 1.04×10^{-7} cm to 1.77×10^{-7} cm. As particles with radii $<3\times10^{-7}$ cm have high diffusion coefficients and are lost to coagulation with larger particles or wall deposition in a few seconds, variations in minimum detectable size are trivial in practical application. A difference in supersaturation will also result in a change in the final size of the water drops formed on the particles. As each droplet is merely counted in an Aitken counter, changes in size cause no change in instrument accuracy.

The drops are photographed in this instrument, by the action of a piston closing a switch at the end of its travel. Variation of expansion can occur, but it is limited to the thermal variation in length of the components which is much less than 1% of total travel. This design effectively eliminates operator error.

4. Verification of performance

The photographic Aitken counters were compared to the ASRC reference Pollak photoelectric nucleus counter Model 1957, with convergent light beam, using the calibration of Pollak and Metnieks (1960). This instrument is the twelfth in a series constructed by R. Gussmann and is the same instrument compared with the Minnesota electrostatic device (Liu *et al.*, 1975), the SANDS and Rosen counters at NCAR (Cadle *et al.*, 1975), and several other replicas of Pollak's counter (Hogan, 1976). The primary purpose of this comparison was to verify the performance of the Aitken counter, and to insure that no leaks, unknown design errors, or other unanticipated phenomena were influencing its operation.

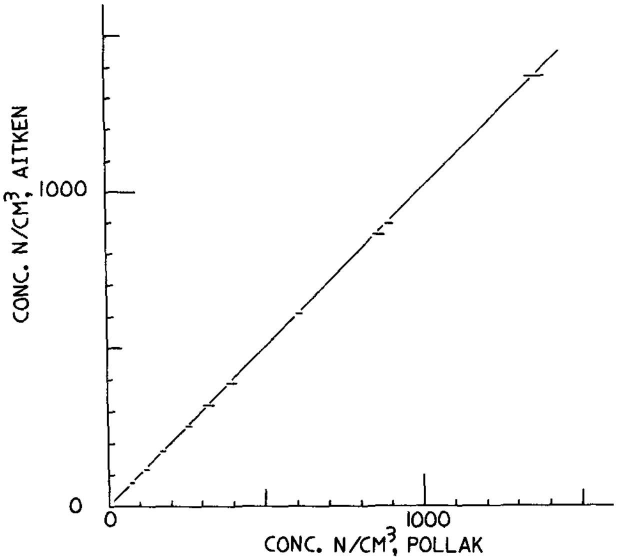


FIG. 3. Concentration measured by the photo Aitken counter plotted as a function of concentration determinations by a Pollak counter prior to, and after, flushing the Aitken counter. The horizontal bars indicate the range of concentrations in the chamber during the period, as established by the Pollak measurement.

The comparison was performed with a polydisperse salt aerosol of about 5×10^{-6} cm mean radius (D. Sinclair, private communication). This is a relatively easy aerosol to generate and dilute, but is a difficult aerosol for most condensation nucleus counters, as it may grow to light-scattering size before expansion (Liu *et al.*, 1975). The results of the comparison are shown in Fig. 3. There is some scatter, due, in part, to sampling error in counting a small number of events and to the finite time required for multiple measurements.

These uncertainties prevent easy confirmation of Pollak's calibration. Indeed, his technique was to establish the aerosol concentration in a "gasometer" by repeated photographic Aitken counts (Metnieks and Pollak, 1959), and then to quantitatively dilute this aerosol for calibration purposes. This comparison answered the initial question and has verified that no gross design or construction errors are present in the photographic Aitken counter.

It should be noted that the comparison ranges from a few tens of particles per cubic centimeter to slightly more than 1000 cm^{-3}. The upper limit of such an Aitken counter is limited by the density of drop images on the film frame; however, a concentration limit of 3000 cm^{-3} is sufficient for measurements in marine and polar regions; higher concentrations of laboratory interest must be measured by quantitative dilution.

5. Conclusions

A photographic Aitken counter has been constructed, which is capable of sensing small aerosol concentrations, such as those typically found in oceanic, arctic and antarctic air masses. The photo-recording feature reduces the magnitude of observer error in obtaining aerosol concentrations in the field.

This instrument was compared with a Pollak Model 1957 photoelectric nucleus counter, with convergent light beam, and was found to be in good agreement. This agreement does not uniquely verify the accuracy of calibration of either instrument. It does verify that field observations obtained with this instrument are directly comparable to early Aitken and Scholz counter observations, and to recent measurements with instruments of Pollak derived calibration.

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