

Jan. 12, 1960

A. V. APPEL ET AL
APPARATUS FOR AUTOMATICALLY COUNTING
AND SIZING AIRBORNE PARTICLES

2,920,525

Filed Aug. 13, 1956

8 Sheets-Sheet 1

Fig. 1.

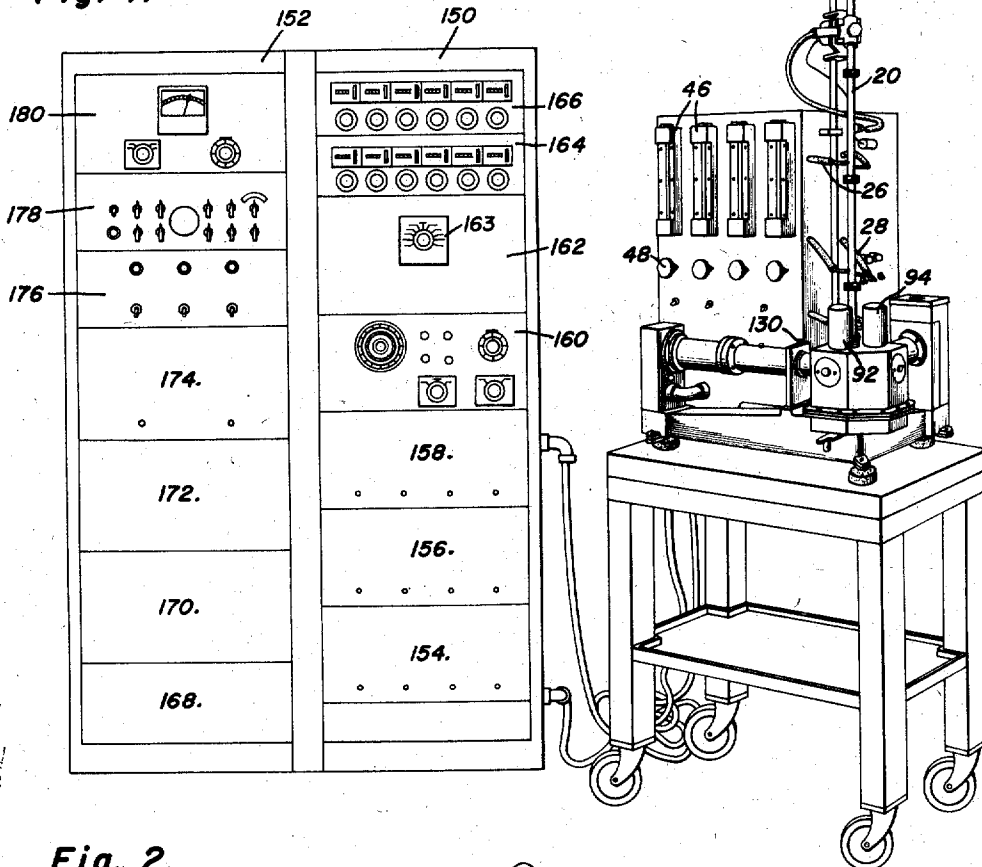
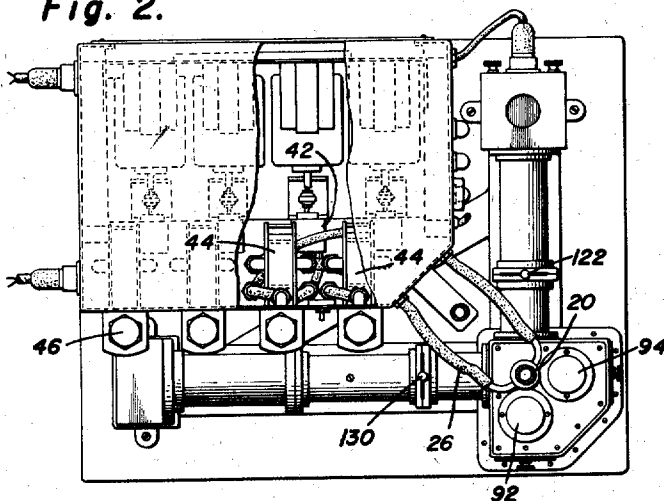


Fig. 2.



Inventors

Arthur V. Appel
Howard T. Betz
Morris A. Fisher
Edward G. Fochtman
Sidney Katz
Alvin Lieberman
Nelson E. Alexander
James L. Murphy
Daine C. Maxwell
Robert E. Lewis

BY *George Penahan*
ATTORNEY

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Fig. 3.

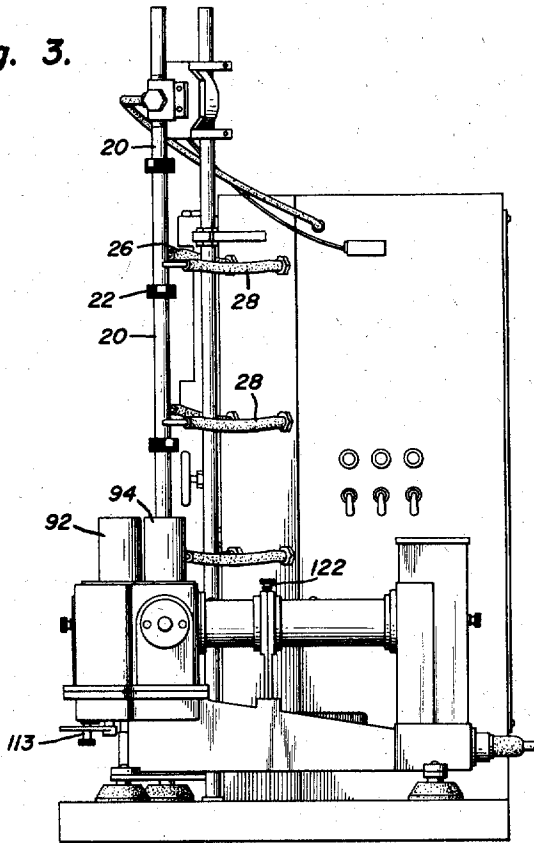


Fig. 4.

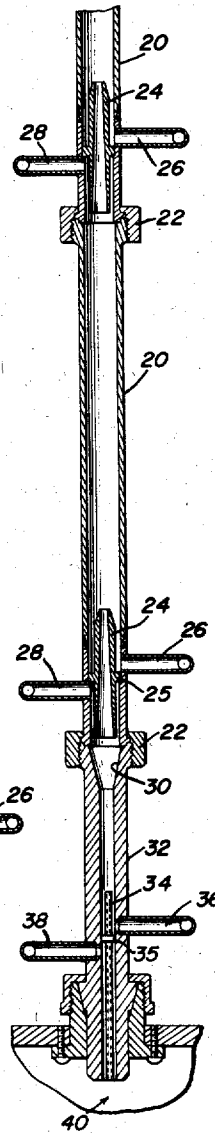


Fig. 5.

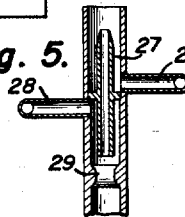
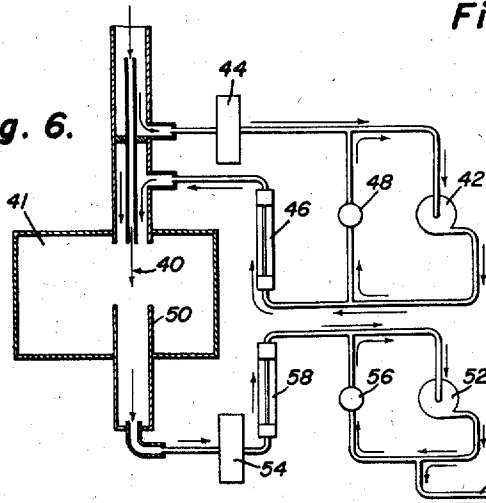


Fig. 6.



Inventors

Arthur V. Appel
Howard T. Betz
Morris A. Fisher
Edward G. Fochtman
Sidney Katz

Alvin Lieberman
Nelson E. Alexander
James L. Murphy
Daine C. Maxwell
Robert E. Lewis

BY *George R. Ruchman*
ATTORNEY

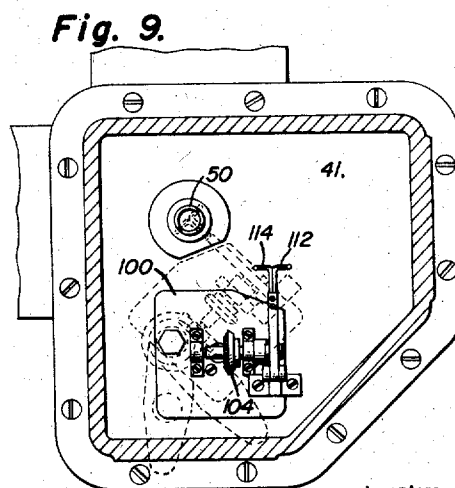
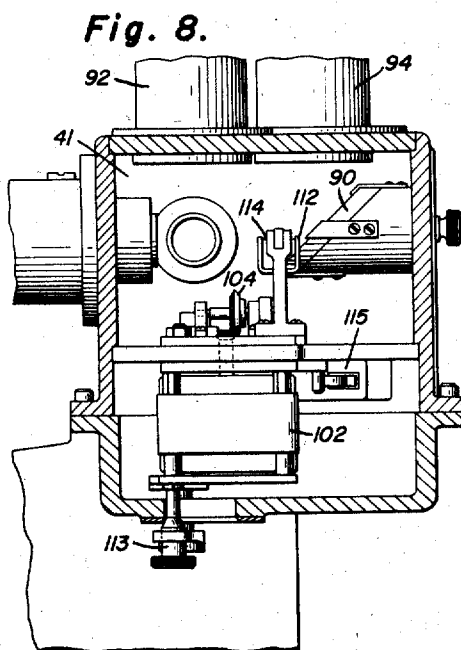
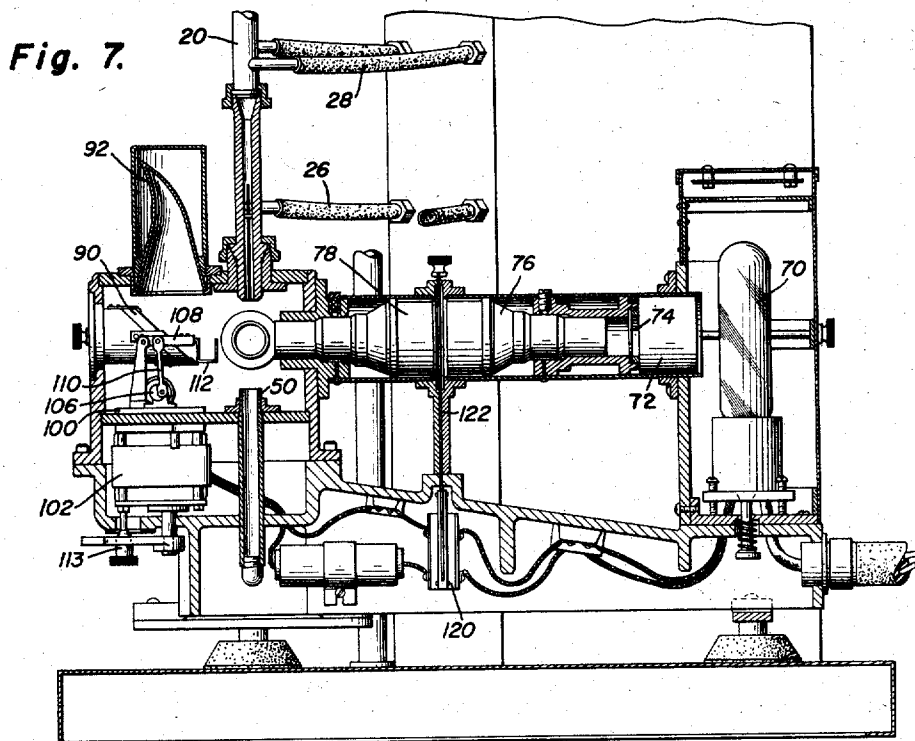
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Inventors

Arthur V. Appel
Howard T. Betz
Morris A. Fisher
Edward G. Fochtman
Sidney Katz

Alvin Lieberman
Nelson E. Alexander
James L. Murphy
Dane C. Maxwell
Robert E. Lewis

BY *George Penckon*
ATTORNEY

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Fig. 10.

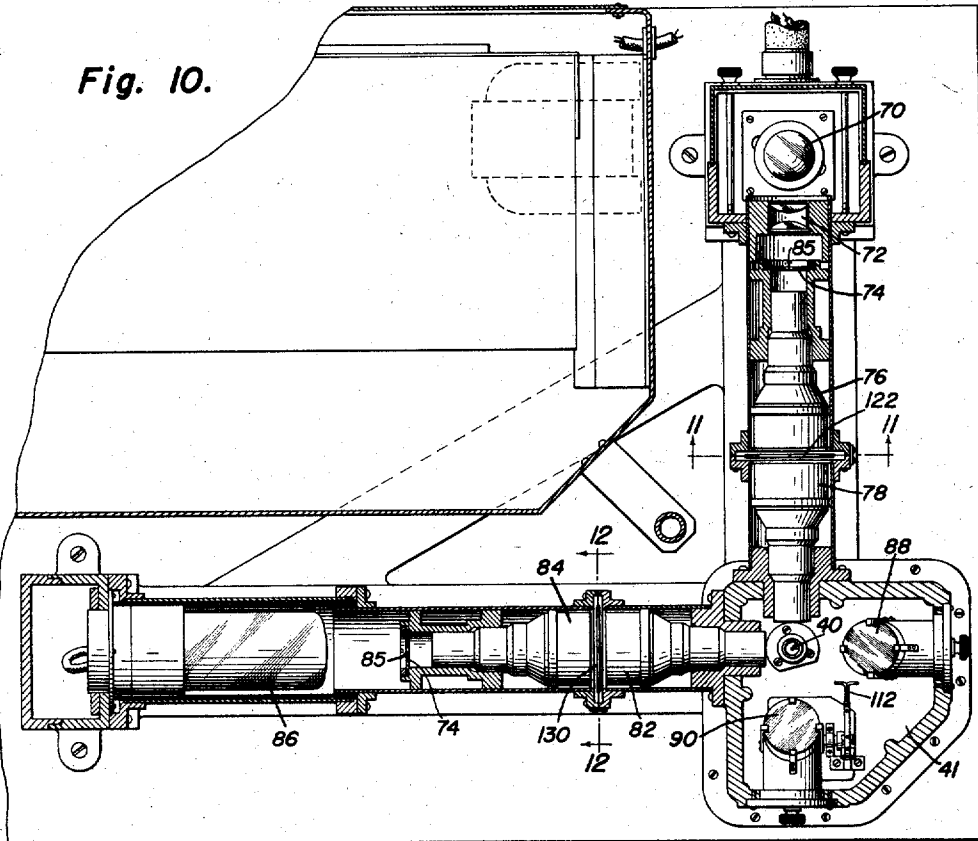


Fig. 11.

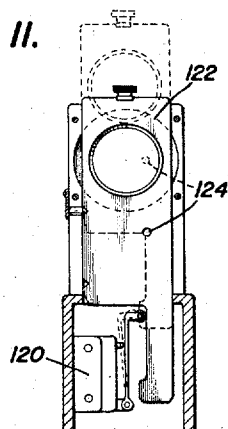
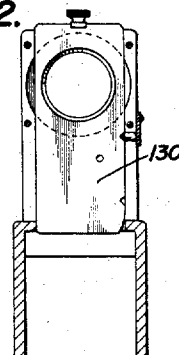


Fig. 12.



Inventors

Arthur V. Appel
Howard T. Betz
Morris A. Fisher
Edward G. Fochtman
Sidney Katz

Alvin Lieberman
Nelson E. Alexander
James L. Murphy
Daine C. Maxwell
Robert E. Lewis

BY *George Penck*
ATTORNEY

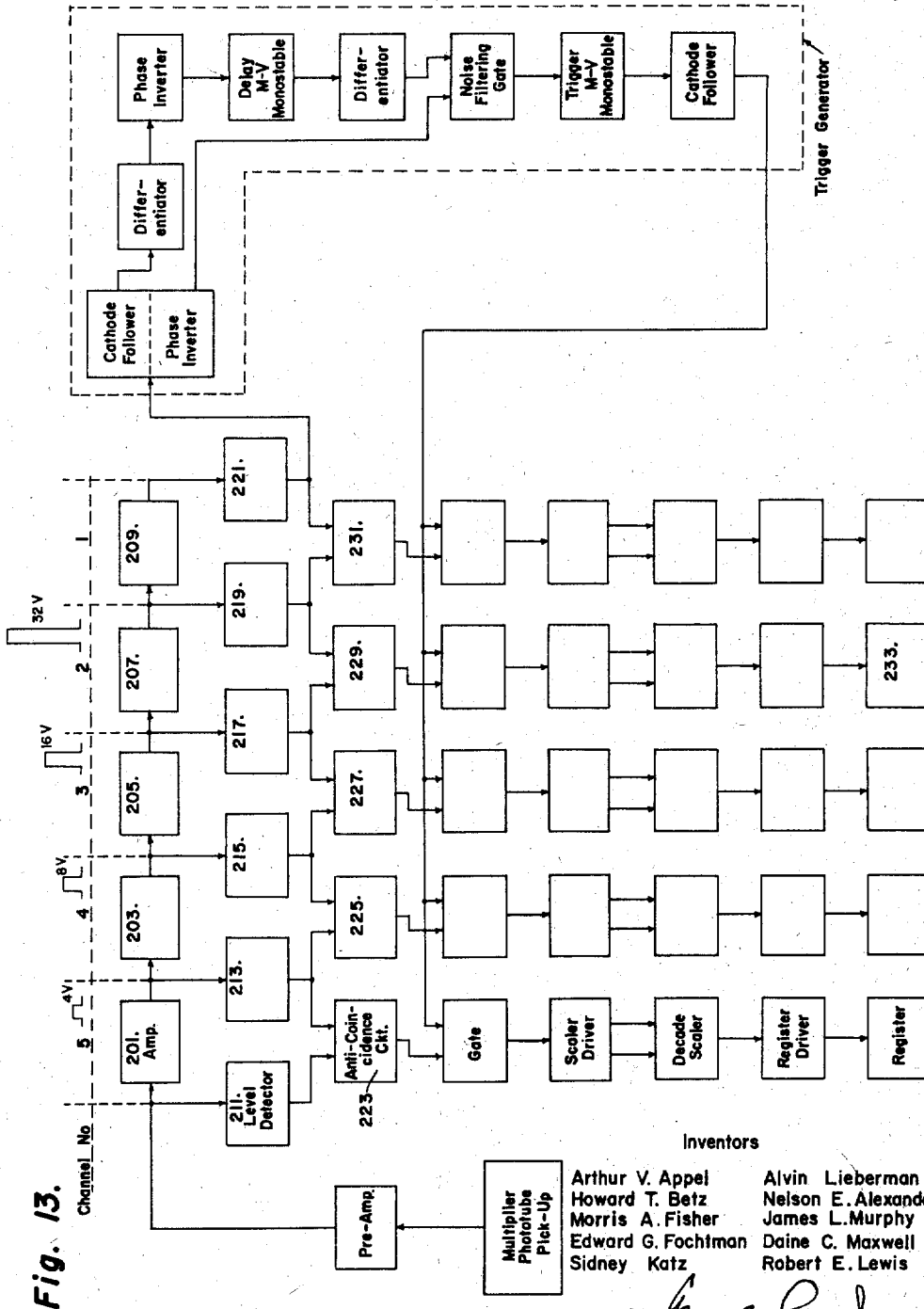
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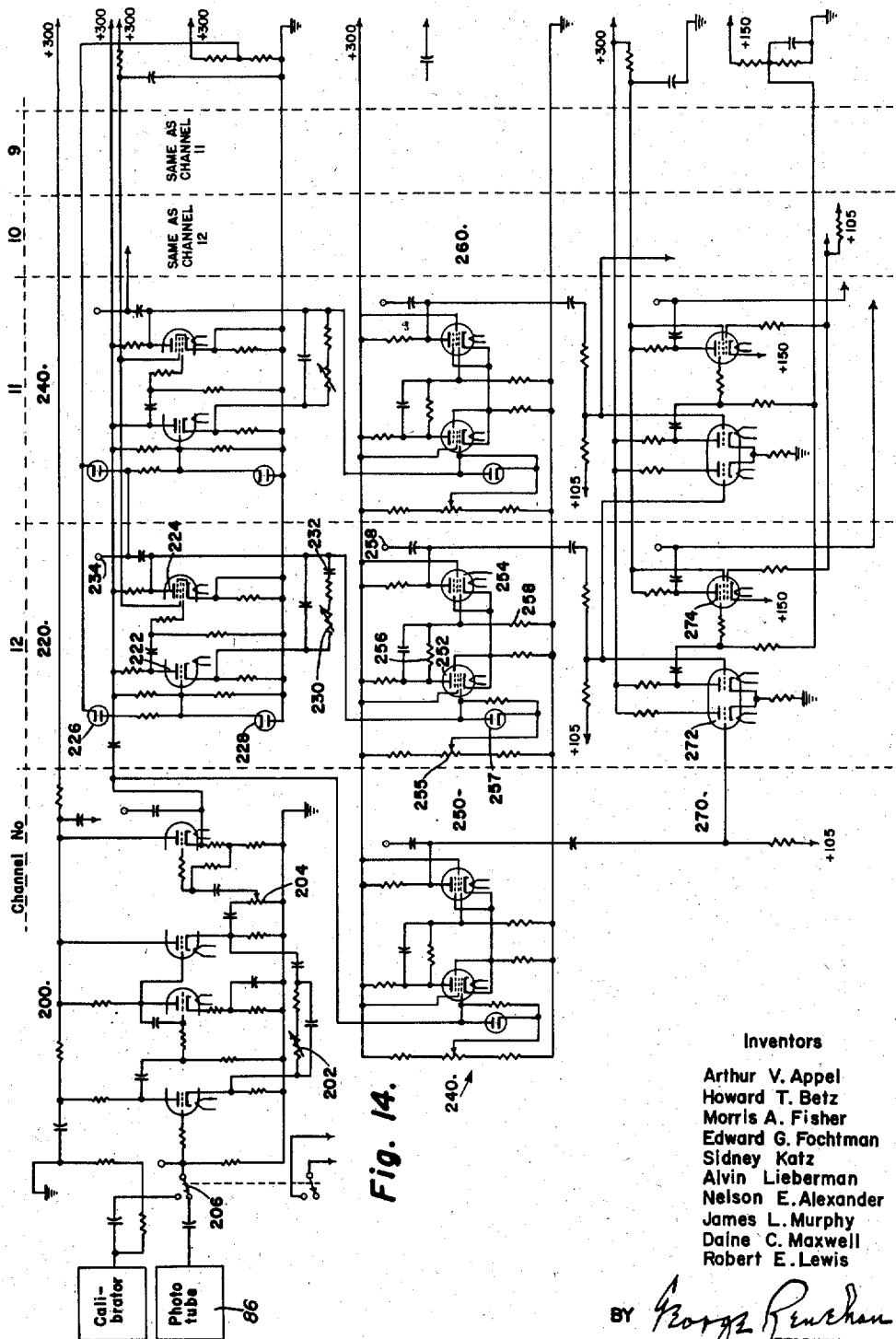
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8 Sheets-Sheet 6



Inventors

Arthur V. Appel
Howard T. Betz
Morris A. Fisher
Edward G. Fochtman
Sidney Katz
Alvin Lieberman
Nelson E. Alexander
James L. Murphy
Daine C. Maxwell
Robert E. Lewis

BY *George R. Ruchman*
ATTORNEY

Jan. 12, 1960

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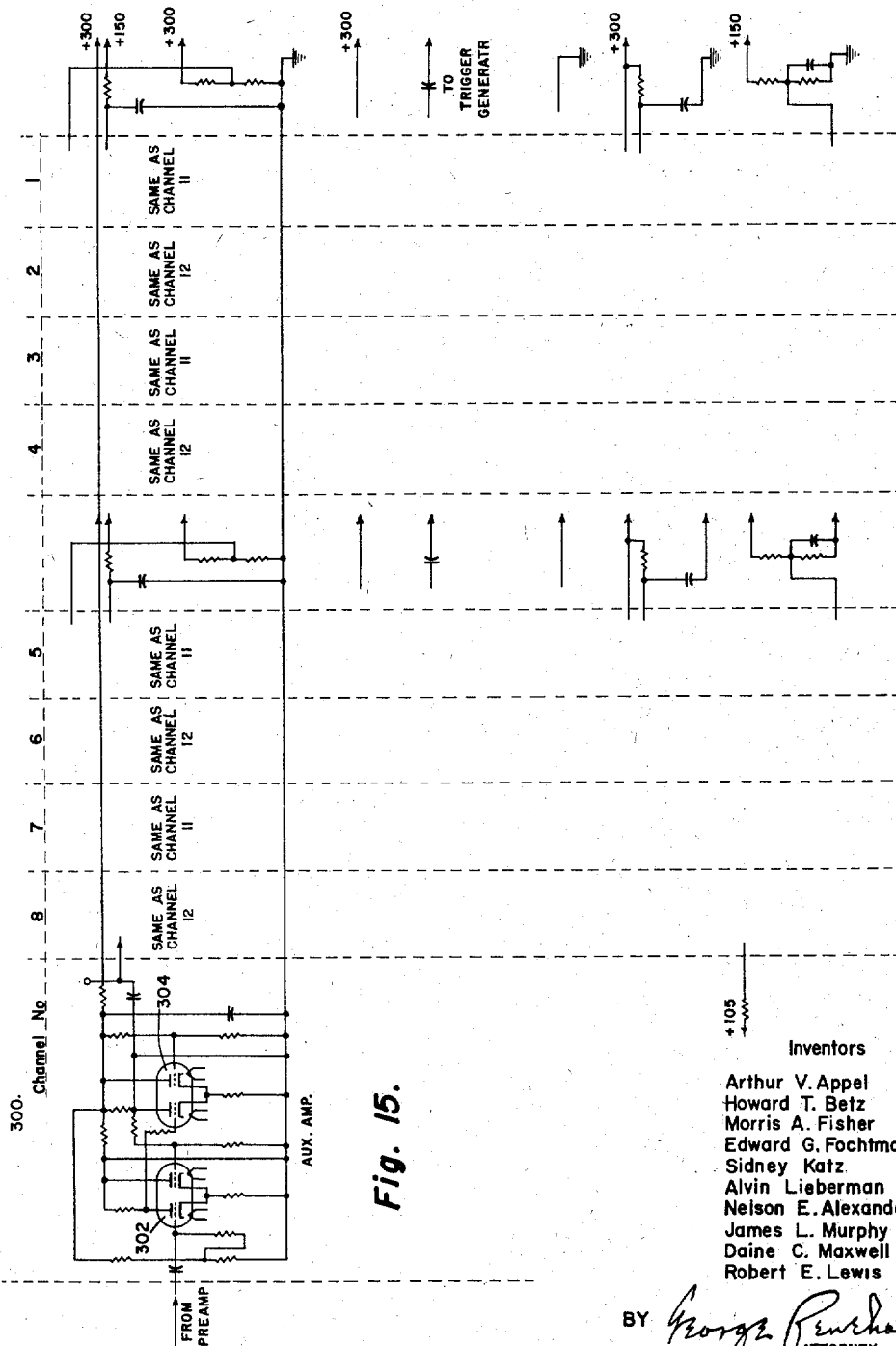


Fig. 15.

Inventors

Arthur V. Appel
Howard T. Betz
Morris A. Fisher
Edward G. Fochtman
Sidney Katz
Alvin Lieberman
Nelson E. Alexander
James L. Murphy
Daine C. Maxwell
Robert E. Lewis

BY *George R. Renshaw*
ATTORNEY

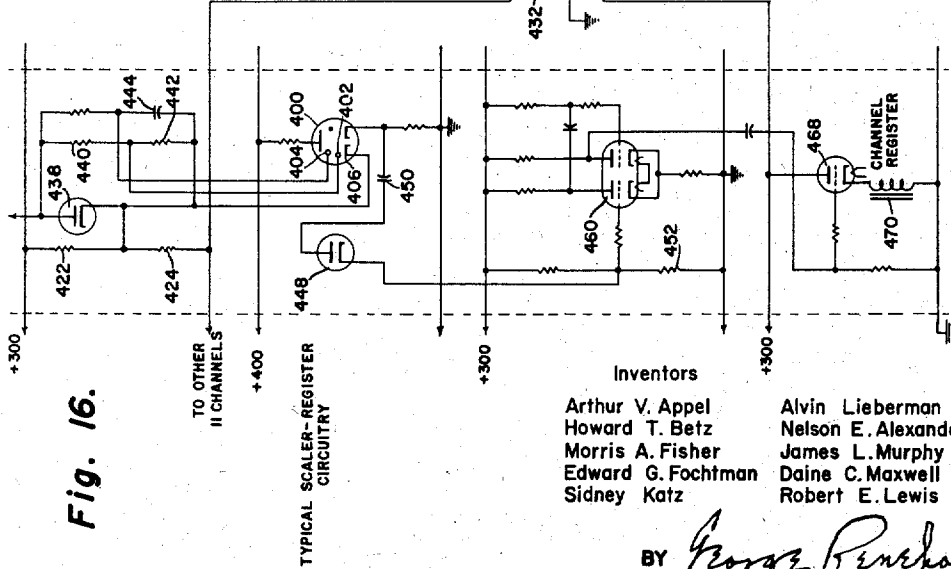
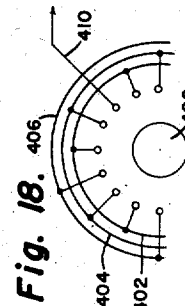
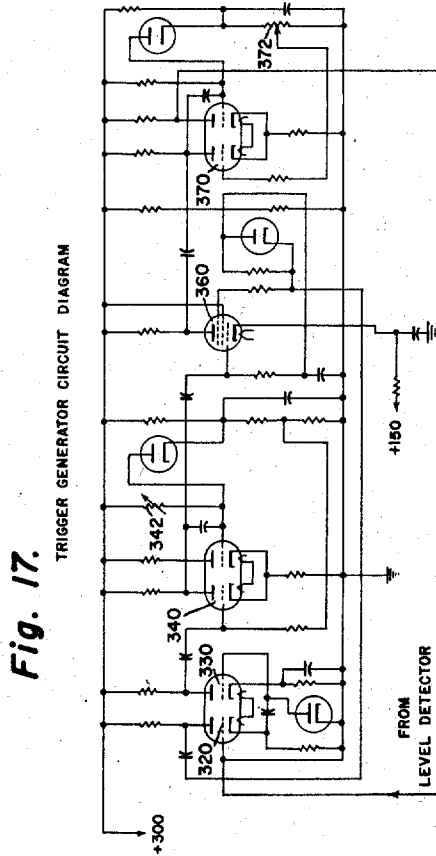
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8 Sheets-Sheet 8



Inventors
Arthur V. Appel
Howard T. Betz
Morris A. Fisher
Edward G. Fochtman
Sidney Katz
Alvin Lieberman
Nelson E. Alexander
James L. Murphy
Daine C. Maxwell
Robert E. Lewis

BY *George Penckon*
ATTORNEY

1

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APPARATUS FOR AUTOMATICALLY COUNTING AND SIZING AIRBORNE PARTICLES

Arthur V. Appel, Chicago, Ill., Howard T. Betz, Chester-
ton, Ind., and Morris A. Fisher, Chicago, Edward G.
Fochtman, Elmhurst, Sidney Katz, Chicago, and Alvin
Lieberman, Skokie, Ill., and Nelson E. Alexander,
Frederick, Md., James L. Murphy, Noroton, Conn.,
Daine C. Maxwell, Madeira, Ohio, and Robert E.
Lewis, Fort Walton Beach, Fla., assignors to the United
States of America as represented by the Secretary of
the Army

Application August 13, 1956, Serial No. 603,853

12 Claims. (Cl. 88—14)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment to us of any royalty thereon.

This invention relates to an apparatus for counting and classifying aerosol particles. More particularly, it relates to an apparatus which is capable of quickly sampling a volume of air containing particulate matter in the range from about 1 to 64 microns in size and of diluting this volume of air to the point where the particles therein may be counted individually by photo-electric means as they pass through a viewing zone.

Specifically, the invention relates to an aerosol control system for such counting mechanism wherein a moving column of air is divided into two parts, one portion of said column of air being diverted and the particulate matter therein filtered out. The filtered air is then returned to and mixed with the undiverted column whereby the number of particles initially in a given volume of air is reduced to some fraction of the original.

Specifically, the invention relates to an optical system wherein a beam of light is focused on a given viewing zone and any light scattered by particulate matter in said viewing zone is analyzed by a corresponding optical system which transforms said scattered light into electrical pulses. Specifically, the invention also relates to a light trap for absorbing and dissipating any irregularly scattered light from said viewing zone.

Specifically, the invention further relates to an electronic system capable of amplifying, measuring and classifying electrical pulses and of registering said pulses in a series of channels at a high rate of speed.

The invention further relates to means for standardizing such optical and electronic systems to maintain constant operational characteristics.

The problem of rapidly counting and classifying the number and size of particles in a volume of air has become of great importance. This is particularly true in view of the large amount of atmospheric contamination occurring in present day industrial areas. The necessity for quick determinations of such contamination is obvious and due to the large number of such particles in a given volume of air, it becomes necessary to count such particles with a high degree of accuracy and at a high rate of speed. The present invention was devised in an effort to accomplish these ends and to count particles in aerosols containing up to 10,000 particles per cc. The machine was devised to register particle diameters in twelve classes ranging from 1 to 64 microns and in steps proportional to the $\sqrt{2}$ to cover the desired size range. The machine was devised to include an air handling system wherein the air was made to flow downwardly in a vertical column and wherein a number of dilution stages could be introduced such that the ultimate particle concentration would be within the counting capacity of the machine. After having been subject to the necessary di-

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lution, the air sample is made to flow through a highly illuminated viewing zone. Any particles passing this zone will scatter and reflect light which impinges on this zone. This scattered light is viewed and sensed by a photoelectric cell properly positioned behind a suitable optical lens system. This photoelectric cell transmits an electrical pulse which is proportional to the scattered light intensity from the particle and therefore generally proportioned to the size of the particle. This electrical pulse passes into an electronic system which amplifies and classifies the resulting pulses into twelve corresponding particle sizes. The pulses actuate the proper counting means which registers the number of particles according to size within a given sample of air.

The detection of particulate matter in this type of apparatus depends upon the principle of the scattering of light by a particle. The intensity of scattered light from an illuminated particle varies with the angular displacement from the incident beam as well as the physical nature and size of the particle and the wave length of the light source. Experimental evidence indicates that there is little choice in sensing white light scattered at wide angles between 30 and about 120° from the incident beam. Although there is some advantage in the forward scattering direction due to the relatively large amount of light transmitted, the physical problems involved make this design inadvisable. Stray light is difficult to eliminate and a rather complicated system is needed to suppress the sensing of light direct from the source. Due to convenience of construction, the present apparatus is designed to sense light scattered at 90° from the incident beam.

In the drawings, Fig. 1 shows a front view of the assembled machine. Fig. 2 shows a top and sectional view of the aerosol control system and optical system. Fig. 3 shows a side view of the aerosol control system and optical system. Fig. 4 shows a section through two air diluter stages and the air sheath assembly. Fig. 5 shows a sectional variation of the diluter of Fig. 4. Fig. 6 shows a diagrammatic view showing the air sheath assembly with its pump, filter, rotameter and by-pass valve together with the viewing zone and the exit air system. Fig. 7 shows a sectional view of the optical system including the lamp, the lens system, aperture slides, the viewing zone, the air sheath assembly, the light trap and the light chopper system. Fig. 8 shows another side view of the optical system including light traps, viewing zone and the light chopper system. Fig. 9 shows a top view of the light chopper system. Fig. 10 shows a top sectional view of the entire optical system including light source, lens system, apertures, viewing zone, photoelectric tube and the light chopper. Fig. 11 shows the dual light aperture together with switches for cutting the illumination when using the light chopper. Fig. 12 shows the light aperture at 12, 12 of Fig. 10. Fig. 13 shows a block representation of electrical circuits and Figs. 14-18 show the electrical circuits and components in greater detail.

The air diluter 20 comprises a vertical column which appears in section in Fig. 4. This diluter is composed of a series of substantially identical sections which are joined together by compression couplings 22. The number of such units which are utilized at any time depends upon the relative concentration of particulate matter in the air. If the concentration of such particulate matter is sufficiently low, it is possible to omit these diluters entirely and to utilize open pipe sections in their stead. When the concentration of particulate matter in the gas to be analyzed is such that there is considerable probability that more than one particle will enter the viewing zone at any one time, it becomes necessary to utilize these diluter sections to reduce the particulate matter by a known amount.

For convenience in calculation, the dilution is carried out in proportions of 10 to 1 in each stage, that is, the central tube 24 of the diluter samples 10% of the air passing through the tube. The remainder of the air passes down the annular space around tube 24, and exits through side tube 26. This exit air is filtered and returned to the main tube through side tube 28 below the transverse wall 25. The shape and length of inner tube 24 is such that the re-entrant air is thoroughly mixed with the central core of air which passes through tube 24. The result is that the air below the first diluter stage now contains 10% of the original particulate matter. As this same volume of air passes the second diluter stage, its content of particulate matter will be reduced to 1%. Any number of diluter stages may be used, although it is rarely necessary to use more than two.

After passing the last diluter stage the air passes into the final air sheath stage 32. This stage is similar in construction to the diluter stages except that the inner tube 34 is longer and has no taper. The result is that the air which is removed at 36 and reenters, after filtering, at 38, does not mix with the sample air passing through tube 34. Instead, it is made to flow in a uniform sheath around the central core of air as it passes through the viewing zone 40.

The individual diluter and air sheath stages are powered by positive displacement pumps 42 having a capacity of 0.3 c.f.m. These pumps draw the air through the exit tubes, through filter 44 and return the air through a flowmeter 46. The latter serves as a continual check on the exact flow rate maintained in the system. Since it is necessary for the diverted air to be moved at substantially the same velocity as the main column of air moving through the system, provision is made to control the air flow by means of a by-pass 48 around pump 42. Although the pump, filter, by-pass and flowmeter units shown in Fig. 6 are for the air sheath stage, the corresponding units in the diluter stages are similar. After passing the viewing zone 40 the air is aspirated from the system by pump 52.

The problem of accurate aerosol sampling is complicated by several factors, one of which is the tendency for the aerosol to settle out. This makes necessary a dynamic air sampling system wherein the air is moved vertically at a constant velocity. When the air is thus moved in a vertical duct, isokinetic sampling may be realized. A further problem in air sampling resides in the necessity of diluting this moving aerosol stream without inducing any changes other than the proportional reduction of particles therein. Since the instrument may be required to determine aerosol concentrations up to ten thousand particles per ml. and since statistical considerations limit the actual counting rate to a maximum of about one hundred particles per ml. at suitable air velocities, dilutions up to one hundred times must be anticipated. Satisfactory dilution requires this reduction of the particle concentration without disturbing the size distribution of the particles and with the least particle deposition on the various surfaces.

To assist in accomplishing this end, diluters 20 are designed with inner sampling tubes 24 having knife-edge bevels at the upper end thereof and with an inner bore which includes a flare angle of about 4° to the vertical. These diluters are found to operate very satisfactorily and to give an accurate dynamic dilution factor when the velocity of the diverted and reentrant air streams are maintained correctly. Thus, when the by-pass air flow through 48 is properly adjusted, the flow of air through the diluter is not appreciably disturbed and the measured pressure drop is then found to be of the order of .003 inch of water.

Other variations in the diluters are possible without departing from this invention. It has been found, for instance, that for all but the lowest size range of particles, a straight bore diluter 27 shown in Fig. 5, instead of

the flared version 24, functions with equal facility. In either type, however, a knife-edge top bevel is essential to correct sampling. A further requisite for good dilution is that the reentrant air at 28 shall thoroughly mix with the air emerging from the diluter inner tube 24. With a sufficiently long unit 20, this normally presents little problem. Turbulence and good mixing is assisted by the divergent flare in the inner tube as well as by a slight constriction 29 in the outer tube. The latter modification is especially effective in connection with the straight bore diluter 27 (Fig. 5).

It has been shown statistically that in counting one hundred particles per ml. the tendency for coincidence counts due to the presence of more than one particle in the viewing zone at the same time is about 5.5% of the particles counted. This is reduced to about .5% when the particle concentration is reduced to 10 per ml. This suggests that even with ten thousand particles per ml. a reduction of 100 to 1, which is accomplished by two diluters in series, will be adequate for most purposes.

Following the dilution steps the air stream is passed through an air sheath stage 32. The air sheath operation is somewhat similar in structure to that of the diluter except that the sampling tube 34 is considerably longer than in the diluter stages, has no flare or constriction and extends a greater distance below the re-entrant air tube 38. The air sheath stage employs a pump, filter, flowmeter and by-pass as in the case of each of the diluter stages. Instead of seeking turbulence and mixing as in the diluter stages, however, the purpose of the air sheath stage is to approximate laminar flow so that when the aerosol stream emerges from the air sheath tube 34 it is surrounded by an annular sheath of aerosol-free air so that the two streams maintain their relative positions between the lower end of the air sheath assembly and the viewing region.

In the upper part of the air sheath stage, the air column is reduced from 12 mm. to 4.75 mm. by conical section 30 and the inner sampling tube 34 has an inner diameter of 1.2 mm. This achieves a ratio of total flow to inner tube flow of about 16 to 1. The metering procedure involves measuring the main flow and the by-pass flow and obtaining the inner flow by differences.

After passing through the viewing zone the aerosol stream is exhausted through exit tube 50. This exhaust system includes a pump 52, a filter 54, by-pass 56 and flowmeter 58. It differs from the dilution and air sheath stages only in that instead of returning the air to the system it is exhausted to the atmosphere through conduit 60. Control of this exhaust rate determines the flow rate through the system.

The optical system whereby the 1.2 mm. stream of diluted air is viewed consists of a light source 70, a condenser 72, an aperture 74 and a projection lens system 76, 78. The latter focuses the aperture on the viewing zone 40. This zone is intensely illuminated in an area of about 1 mm. high and 3 mm. in cross section which corresponds to the size of aperture 74. Although the illumination is uniform only in the focal plane of the image, the variation due to depth of aerosol stream is not great. Measurements taken in the plane at 1 mm. before and 1 mm. behind the focus showed variations of less than 5%. The viewing zone may therefore be regarded as uniformly illuminated throughout to within 5%.

The light source is a tungsten ribbon incandescent lamp rated at 18 amperes and 6 volts. The condensing lens is a 3 element compound system of 51 mm. focal length. Its function is to produce an image of the filament on aperture 74 which thus becomes the effective light source for the system. The projection lenses are $f/2$ Petzval type motion picture projector lenses of 76 mm. focal length, with non-reflective coatings at all air-glass surfaces. The image of the aperture is produced at the center of the aerosol stream in viewing zone 40.

The viewing lens system consists of a projection lens system identical with that used to focus the incident light and consists of the two elements 82 and 84. It is positioned at 90° to the incident beam. This viewing lens system transmits the image of the viewing region through the exit aperture 85 to an end-on type photomultiplier tube 86. As a means of minimizing scattered light effects within the optical chamber 41, two deeply colored glass surfaces 88 and 90 are positioned at 45° to the respective optical axis of the incident and viewing light beams. These surfaces absorb a large proportion of unwanted, stray light which is then reflected into horn shaped, dark glass, or ceramic light traps 92 and 94. The light reaching the inside of these traps is reflected repeatedly from surface to surface until its intensity is reduced almost to zero. Both surfaces 88 and 90 as well as light traps 92 and 94 are primarily light absorbers and the small proportion of incident light that is not absorbed in the interior is reflected at the surface.

The inside of chamber 41 is finished in black matte which serves to absorb stray light and reduce the amount to be dissipated in the light traps.

This optical system scans the particles successively as they pass through the viewing zone at rates of about 1500 to 1800 mm./sec. In accordance with the latter velocity, the larger particles will traverse the 1 mm. viewing cell in 550 μ seconds, which is therefore the duration of the pulse generated by the particle. The latter pulse length is considerably greater than that of any noise pulses appearing in the system, hence a comparable choice of aerosol velocity makes possible very satisfactory noise suppression in the system.

It will appear from this description that the viewing zone is optically defined in height only, the lateral dimension being defined by the diameter of the aerosol stream.

It is obvious that width as well as height of the viewing zone may be determined optically. Thus, if the illumination is limited in two dimensions and the same is done for the viewing field, the resulting viewing zone is automatically defined as a cubical volume in space irrespective of the size of the aerosol stream. This makes it possible to use a large aerosol stream and to define the viewing zone wholly by optical means within the stream.

This concept of an optically defined viewing zone may be used with or without the dilution process depending upon the initial concentration of the aerosol. This method also renders the air sheath unnecessary since the boundaries of the aerosol stream are no longer called upon to define the lateral boundary of the viewing zone.

To calibrate the optical system a light chopper 100 is provided. This apparatus is pivotally mounted on the bottom plate of the viewing chamber. It consists of a synchronous motor 102 driving a pinion and ring speed reducing gears 104. These, in turn, drive eccentric crank 106 which is connected to swinging arm 108 by means of connecting rod 110. The swinging arm terminates in a fork 112 across which is stretched a .0008 in. diameter Nichrome wire 114. The entire assembly, including the motor, pivots about an axis such that the wire can be swung into and out of the viewing zone. When it is pivoted into the viewing zone, the reciprocating motion of the wire intercepts the viewing zone and scatters the light intermittently in the manner of a particle, thereby generating a calibrating signal. The chopper generates 40 pulses/sec. of about 600 μ second duration. The velocity of the wire in passing through the viewing zone is essentially the same as the velocity of a particle traversing the same zone. The signal produced by this calibrator is used to standardize the optical part of the system.

A microswitch 115 is mounted under the bottom plate of the viewing chamber and is positioned such that it is actuated by the swinging chopper assembly. This switch, together with a second microswitch 120, is connected in interlock relation with the source lamp 70. This second

microswitch is positioned such that it is actuated by attenuator slide 122 (Fig. 11). It is mounted between the two pairs of lens tubes 76 and 78 and can occupy two positions determined by a detent. In the operating or "down" position the slide passes all the light coming from the source whereas in the "up" or calibrating position a small off-center aperture 124 admits only a small proportion of the source light. Since the larger and more reflective surface of the chopper wire 114 scatters much more light than even the largest particle, aperture 124 serves to reduce the illumination to a level such that the light scattered by the wire is of the same order of intensity as that scattered by a given size particle in a non-attenuated beam. When the calibrator is swung into position at the viewing zone, the lamp source cannot be activated until the aperture slide actuates microswitch 120 by being in the "up" position. Thus the reduced illumination prevents overloading of the photomultiplier when the calibrator is in use. Attenuating slide 130, (Fig. 12), between collection optics 82 and 84, is structurally similar to slide 122 and reduces the light level to a still lower value when in the "up" position.

To aid in correctly aligning the optical and aerosol systems an alignment point can be inserted in the exit tube 50. This point serves to align the inlet and exit aerosol tubes, to focus the illuminated area correctly on the axis of the aerosol stream and to position the calibrator system so that the wire properly intersects the illuminated area.

The entire chamber 41 is air tight, seals being provided for the calibrator positioning lever 113 as well as for electrical connections to the chamber.

Following the generation of a pulse by the photomultiplier, it is passed into the electronics section which amplifies and classifies the pulse as to magnitude and registers it in one of the twelve channels of the instrument.

An understanding of the functioning of the electronics section can best be accomplished by a study of a simplified block diagram of the system as shown in Fig. 13. This diagram has the components labeled and the potential variations of the signal appears above the respective stages. Only five channels are shown and are illustrative of the twelve channels in the machine.

The magnitude of the input signals to the system are determined principally by the intensity of scattered light from the aerosol particles which in turn is proportional to the size of the individual particles. The twelve size ranges or channels into which the overall range (1 to 64 μ) is divided each have a width ratio of $\sqrt{2}$, that is the ratio of the diameter of the largest particle in any one size range to that of the smallest in that range is as $\sqrt{2}$ is to 1. The level of light scattered by a particle passing through the viewing cell of the optical system is nearly proportional to the square of the particle diameter. The photomultiplier in the pick-up unit converts this light information into an electrical pulse, the amplitude of which is proportional to the intensity of the scattered light. It follows, therefore, that in terms of the amplitude of the electrical pulse from the photomultiplier, the width ratio of each particle size range or channel is $(\sqrt{2})^2$ or 2.

With few exceptions, only one particle will appear in the viewing cell at any one time. As a result, the output signal consists of a series of nearly rectangular pulses, one for each particle viewed. The width of each pulse is the particle transit time through the cell or about 500 to 600 μ sec. and its amplitude is generally proportional to the square of the particle diameter. In the electronic system these pulses are sorted into twelve channels according to amplitude and are registered in the proper channel.

In the block diagram (Fig. 13) 201, 203, 205, 207 and 209 represent tandem amplifiers, each with a gain of 2. Assuming a 2 volt signal at the exit of the preamplifier, then through voltage doubling at each stage, the magni-

tude of the voltages will appear as shown above each stage. At the output of each amplifier are level detectors 211, 213, 215, 217, 219 and 221 which function in a manner to produce output signals only when the channel amplifier produces a pulse exceeding a pre-set level of 20 volts. Below the level detectors are a series of anti-coincidence circuits 223, 225, 227, 229 and 231, each of which may receive an input signal from two consecutive level detectors. Any of these coincidence circuits may function to transfer signals to the following gate and register only when it receives an impulse from only one of the two level detectors with which it is associated:

The given 2 volt signal will exceed the required 20 volts at level detectors 219 and 221. These detectors will feed signals in turn to anti-coincidence circuits 229 and 231. In 229 only one signal is received whereas 231 receives signals from two sources and 227 receives no signals. Thus, only circuit 229 responds to the signal and register 233 tallies up the particle. This shows that the pulse originated from a particle in the second size range.

From this analysis it can be seen that if a particle were $\sqrt{2}$ as large it would have twice the signal strength and the particle would then be tallied up in the third size range.

In the complete twelve channel instrument the principle of operation is basically the same as in this simplified five channel unit. In each case the signal is fed through a series of channel amplifiers, and on to level detectors and anti-coincidence circuits. A pulse also simultaneously passes from the first channel level detector to a trigger generator. The trigger generator system shown at the right in Fig. 13 serves to delay the transfer of the pulses to the registers. With the proper delay time; the possibility of counting any one particle more than once is virtually eliminated as is the tendency to count sporadic noise pulses of short duration. In other words, this delay mechanism insures that long pulses will be counted only once and short pulses not at all.

The electronics components are housed in separate cabinets 150 and 152. More particularly, behind panels 154, 156 and 158 are found the series of twelve discriminators for the twelve channels or particle ranges. Panel 160 includes the preamplifier and trigger generator. Panel 162 includes the calibrator and control, and panels 164 and 166 include the read out chassis with six electronic decade scalars and six electro mechanical registers on each panel for the total of twelve channels.

In cabinet 152 are found the plate and filament voltage supplies and controls behind panels 168, 170, 172 and 174. A power control panel appears at 176. An oscilloscope for visually checking the electronic functioning appears at 178 and a dynode power supply at 180.

Detailed circuits of the electronic system appear in Figs. 14 to 18.

After a pulse has been generated by the photomultiplier tube 86, it passes to a preamplifier 200 (Fig. 14). This preamplifier consists of two dual triodes. The first two triode sections have conventional capacitive coupling whereas the third triode is direct coupled to the second and functions as a cathode follower. A variable voltage feedback loop appears between the cathode follower output and the cathode of the first triode. The last triode section also functions as a cathode follower output and is preceded by a gain control. The condenser in parallel with the feedback resistor limits the high frequency response of the unit and the resistors in series with the control grids prevent blocking by unduly large signals. Frequency response is essentially flat up to about 10,000 c.p.s. Switch 206 at the input of the preamplifier permits a selection of the signals from the calibrator or from the photomultiplier unit as the case may be. One section of this switch also supplies plate voltage to the calibrator section when in the calibrate position. The preamplifier serves to increase the amplitude of the sig-

nals from the photomultiplier before application to the discriminator. It has a gain of 20 and adjustment of the feedback control 202 may be made to maintain this value.

Following the preamplifier, the signal passes into a series of twelve channel amplifiers. All of these amplifiers are basically similar and consist of a triode 222 and a pentode 224 with capacitive coupling and stabilized with about 28 db voltage feedback from the plate of the pentode to the cathode of the triode. This feedback loop is variable through control 230. The values of components are chosen and feedback is adjusted to reduce the overall gain to 2. The presence of the two tubes in series insures that no phase reversal takes place in the circuit.

Gain control 204 is used for adjusting the system to the proper value for the particular aerosol under study. Diode 226 serves as a D.C. restorer to return the base line of the incoming signal pulses to a fixed value following each pulse. Diode 228 limits the maximum signal at the input grid thereby to prevent overloading and blocking in the amplifier in the following level detector.

The channel amplifiers are all identical except that the even numbered ones, i.e. 12, 10, 8, 6, 4 and 2 contain a .13 mfd. capacitor 232 in the feedback loop. This serves to introduce a low frequency boost and to reduce the pulse distortion in the later amplifiers from upper range input pulses.

Even with this compensation, however, it was not feasible to pass signals through the entire series of twelve channel amplifiers. To reduce the number of coupling networks through which the signal pulses must pass, the signal was passed simultaneously to channel amplifier 12 and channel amplifier 8. Thus, the first four channels were by-passed with the auxiliary amplifier 300 (Fig. 15).

This amplifier unit consists of two double triodes 302 and 304 and is basically a two stage direct coupled amplifier with negative voltage feedback for gain stability. It is non-blocking and self limiting. It has a gain of 16 which is equivalent to the gain of the first four channel amplifiers which it by-passes. The presence of this amplifier greatly reduced the level of electrical noise in the system.

The level detectors are shown in 240, 250 and 260, Fig. 14. They establish the boundaries between adjacent particle-size ranges. They are basically Schmitt trigger type circuits as described in Time Basis 1943, John Wiley and Sons, Inc., New York and consist of two pentodes 252 and 254 in series having a common cathode resistor.

Under steady state conditions with no signal applied, the circuit remains in a stable state with 252 conducting due to the positive value of its grid return, whereas 254 is cut off due to voltage divider action of resistors 256 and 258. If the grid potential of 252 is lowered to a certain value, the conduction of this tube will be decreased to the point where, due to the drop of the common cathode voltage and the rise in 252 plate voltage, pentode 254 will begin to conduct. This will cause a regenerative action and the conduction will abruptly change from 252 to 254. When the grid voltage of 252 is now raised by a small amount the action reverses and the original state is restored. Thus a negative square output pulse of uniform amplitude is obtained at the plate of 254 for every negative pulse at the grid of 252, which pulse is large enough to cause the triggering action. Potentiometer 255 is adjusted so that a pulse of 20 volts or more will trigger the circuit. Diode 257 acts as a D.C. restorer to prevent the baseline from rising in potential due to a rapid series of pulses.

To set the bias, by means of potentiometer 255, tubes 222 and 224 are removed and a 20 volt negative pulse of about 600 μ sec. duration is applied to jack 234 in the plate terminal of tube 224. Potentiometer 255 is adjusted until the level detector is just triggered by the

pulse. This can be determined by observing the output at the plate of 254 at 258 on an oscilloscope.

The position of the trigger generator in the overall circuit is shown in Fig. 13 and the circuit details are shown in Fig. 17. It will be seen that the input of the unit is obtained from the level detector following channel amplifier No. 1. Since this level detector triggers from the pulse of a 1.0 micron particle or larger, the trigger generator will receive an input from every particle to be counted.

The purpose of this unit is the production of a 100 μ sec. registering pulse at a suitable time after the initiation of the signal pulse by a particle passing through the optical unit. This delay enables the signal pulse to reach maximum amplitude and for all the appropriate level detectors to trigger.

The trigger generator unit consists essentially of a delay multivibrator, a gate circuit and a multivibrator for generating the register pulse. The operation of the unit is as follows: the output from the channel 1 level detector is inverted in triode 320 and applied to the suppressor grid of gate pentode 360. This same pulse is also differentiated, amplified and inverted in triode 330 and the leading edge of the pulse is used to trigger 340, a monostable delay multivibrator. The multivibrator output pulse, which is normally of 250 μ sec. duration is differentiated and the resulting trailing edge spike is applied to the control grid of the 360 gate pentode. If at this time, the detector output pulse still persists, the gate is open and the spike passes through to trigger multivibrator 370 (second duration) which generates the 100 μ sec. register pulse. Triode 380 serves as a cathode follower output.

With this system, level detector output pulses shorter than the 250 μ sec. delay time will not result in the generation of a register pulse since gate 360 will be closed before the arrival of the pulse for actuating the register pulse multivibrator. Thus, short noise pulses and erroneous signal pulses are discriminated against. The delay time is determined by the setting of the potentiometer 342. Normally, this control should be set for about 250 to 400 μ sec. delay time. The register pulse duration is controlled by control 372 and should be set for about 70 to 100 μ sec.

The anti-coincidence circuits shown at 270 determine the level detector associated with the smallest size measuring channel to be triggered by each signal pulse. Each stage consists of a dual triode 272 and a pentode 274. The triode has a common cathode and is biased to about 105 volts positive in the quiescent state. Only the right triode is coupled to the succeeding gate pentode 274 and when only one signal reaches the triode it arrives at the right section, the conductivity of which is then sufficient to pass a pulse that will open the gate circuit. When signals arrive at both triode sections, the conductivity of each is lessened and the right section is no longer capable of passing the necessary pulse to open the gate.

Gate pentode 274 has its control grid connected to the trigger generator, whereas the suppressor grid is coupled to the second section plate of 272. Both grids are biased well below cutoff due to the relative grid and cathode returns.

If a single negative pulse arrives at the grid of triode 272 a corresponding positive pulse will appear at the suppressor of 274 and will be of a value large enough to drive the grid to zero bias. When the 250 μ sec. delayed triggering pulse of 100 μ sec. duration arrives at the gate control grid, it drives this also to zero bias. Plate current then flows and a pulse is sent to the scaler drive for registering.

Two types of counters are employed in the final register. To obtain the required counting rate, a moderate speed electronic decade counter is used in the first stage. Following this is a four digit electromechanical register

which provides a high count capacity register in a minimum space.

The electronic counter used is a scale-of-ten cold cathode glow discharge counter tube GCI0B type manufactured by Ericsson Telephones (Fig. 18). The counter is operated directly by the output pulses from the gate circuits through the driver circuitry shown in Fig. 16. The count is indicated by the position of the glow discharge within the tube. Each input pulse causes the glow to transfer 36°, thus indicating another count. On the tenth pulse, which marks a complete circuit of the counter, an output pulse is obtained. This pulse is used to actuate the electromechanical register driver circuit. The tube may be operated at a maximum counting rate of 2000 counts per second. The mechanical register, however, is limited to about 15–20 counts per sec. to insure maximum reliability. This means that, for any one channel, the particle counting rate should be limited to about 150 particles/sec.

More specifically, the scaler tube consists of 30 parallel rods which act as emitters, equidistant spaced around a thin, flat disc 400 which serves as anode. The rods are connected in three separate circuits 402, 404, and 406, called guides 1 and 2 and cathodes respectively. The thirtieth rod, 410, has a separate connection.

In the quiescent state, a glow discharge will exist between a given cathode 406 and the anode 400. With every input to the scaler driver, the glow transfers to the next cathode and with every tenth input the glow completes one revolution around the anode and produces an output at cathode 410. Five connections are brought out at the tube base, namely anode, guides 1 and 2, cathode, output cathode. Guides 1 and 2 (402 and 404) are returned to a positive potential of about 20 volts formed by dividers 422 and 424. Since the cathodes are returned to ground through the reset switch 430, a glow forms at one of the cathodes which are all more negative than the guides. Both guides 402 and 404 are driven by the 100 volt negative input pulse from the channel gate. The impulse to 402 which is fed from voltage divider 440–442 reaches one half the value of the input pulse immediately, whereas the input to guide 404 rises toward the full value at an exponential rate due to the charging of capacitor 444. With the leading edge of the input pulse, guides 402 are driven below ground so the glow transfers from a cathode to the adjacent guide. When guides 404 have become more negative than that of guide 402, the glow transfers to the adjacent guide 404. After the input signal pulse is over and the cathodes are again the most negative electrodes, the glow makes a third transfer to the adjacent cathode 406, completing the cycle.

Each time the glow arrives at the output cathode, the positive step of voltage is differentiated by capacitor 450 and resistor 452 and applied to the dual triode 460 which functions as a monostable multivibrator. This unit forms a 20 millisecond positive pulse which actuates the register 470 through cathode follower 468. Diode 430 acts as a D.C. restorer whereas diode 448 in the differentiator circuit blocks the negative spike which is caused by the glow moving from the output cathode to the next position, so that the multivibrator 460 will not be switched back to its monostable state before the end of the 20 millisecond period.

Resetting the scaler tube is accomplished by raising the guides and cathodes 402, 404, 406 to a high positive potential by opening the short across resistor 432 by means of scaler reset 430 and thereby causing the glow to jump to the output cathode or zero position. The second contact in 430 prevents the register from being actuated during the resetting operation.

Voltage requirements of the system are as shown. Voltage supplies are conventional and stabilized to thereby maintain the system in equilibrium and to obviate the requirement for frequent calibration.

The aerosol handling and sensing portion of the instrument is standardized by means of the fine wire and light chopper combination previously described. The preamplifier and pulse height discriminators are standardized by means of the electronic calibrator 162. This device produces a pair of consecutive 650 microsecond pulses at a certain repetition rate, one pulse of the pair having 10% greater amplitude than the other. These pulses are attenuated in a thirteen position precision step attenuator 163 in such a manner that at position "13" the pulse height of the smaller of the two pulses is equal to that from a 64 micron particle. In position "1" the pulse height of the larger of the two pulses is equal to that of a one micron particle. In positions "2" through "12," the pulse height is equal to the boundary value between adjacent channels for the 12 respective channels. Thus by design, the mean pulse height at each position of the attenuator bears a 2 to 1 relationship with that of the adjacent position. The output of this attenuator is fed to the input of the system when switch 260 is in "calibrate" position. Beginning with position 13, the gain of the preamplifier 200 is standardized by means of potentiometer 204. The gain of each of the channel amplifiers is checked or adjusted for each succeeding position of the switch so that the two pulses standardize each channel boundary. For example, in position No. 8 the gain of channel amplifier 8 is adjusted so that the larger of the pair of pulses is counted in channel 8 and the smaller in channel 7. Since the heights of the two pulses are ten percent apart, the boundary between channel 8 and 7 is defined as plus or minus 5% after calibration. If the initial gain of amplifier 8 is low, both pulses will fall into channel 7, giving this channel a double counting rate. Likewise, if the gain of the amplifier is too high, channel 8 will receive both pulses, giving it a double counting rate. Thus, this electronic calibrator yields a rapid and accurate means of standardizing and checking standardization of the pulse height discriminators and preamplifier. The gain of the preamplifier is adjusted to a standardization value with the step attenuator switch in position "13." In this position only the smaller of the two pulses should be counted in channel 12 as indicated by a single counting rate. Thus, the preamplifier can be adjusted so that channel 12 counts only the smaller of the two pulses corresponding to the 64 micron particle but does not count the larger of the two pulses corresponding to a particle 10% larger than this.

After the pulse height discriminators and the preamplifier gains are standardized, switch 206 is changed to the "Phototube" position and the pulse from the fine wire standard (chopper) is presented to the preamplifier and discriminator system. The 0.0008 inch diameter Nichrome wire, it has been found experimentally, is about equivalent to a 5.6 micron diameter particle with this design of optical system. The gain of the multiplier phototube may then be adjusted or standardized so that half of the standard pulses fall in channel 5 and half fall in channel 6. Since the boundary between those two channels is by definition 5.6 microns, standardization of the system is complete.

When operating the machine to determine the amount and size of particulate matter in a given volume of air, it is only necessary to operate the machine for a given time, add the total particles registered in the respective channels, multiply the latter by the dilution factor and calculate volume by rate of flow and time. In the machine described, the dilution factor will be 1600 to 1, 160 to 1 or 16 to 1, depending upon whether two, one or no diluters are used respectively.

We claim:

1. A system for detecting, measuring and counting particulate matter in a fluid which comprises an aerosol handling system including a diluter wherein a portion of the aerosol flow is withdrawn, filtered and returned to the aerosol stream, thereby reducing the particulate matter

per unit volume of the aerosol stream, optical means for illuminating a viewing zone in an aerosol stream produced by said system, further means for optically detecting the amount of light scattered by aerosol particles traversing said viewing zone, means for translating said scattered light into discrete electrical pulses, electronic means for amplifying and classifying said pulses into groups on the basis of magnitude and means for registering said pulses on registers in separate channels of the instrument.

2. A system for detecting, measuring and counting particulate matter in a fluid which comprises an aerosol handling system, optical means for illuminating a viewing zone in an aerosol stream produced by said system, further means for optically detecting the amount of light scattered by aerosol particles traversing said viewing zone, means for translating said scattered light into discrete electrical pulses, electronic means for amplifying and classifying said pulses, said electronic means comprising tandem channel amplifiers having fixed gain, level detectors associated with each amplifier, an anti-coincidence circuit associated with each of two adjacent level detectors, each of said anti-coincidence circuits being in turn associated with a numerical register, said level detectors serving to sample the magnitude of the signal before and after each amplifier and to pass on a second signal whenever the sampled signal reaches a value, preset for each level detector, said second signals passing to the anti-coincidence circuits, the second signals from the level detectors before and after a tandem amplifier, passing to a common anti-coincidence circuit, said anti-coincidence circuit serving to pass on a third signal to the numerical register whenever the anti-coincidence circuit receives the second signal from only one level detector.

3. A system for detecting, measuring and counting particulate matter in a fluid, which comprises an aerosol handling system; optical means for illuminating a viewing zone in an aerosol stream produced by said system; further means for optically detecting the amount of light scattered by aerosol particles traversing said viewing zone; said optical illuminating and detecting means comprising in series a light source, a condensing system, an aperture, dual projection lenses, positioned back to back to permit passage of parallel light from one to the other, and having said aperture at the focal point of the first projection lens, and having an illuminated viewing zone at the focal point of the second projection lens, a second optical viewing system positioned at an angle with said first illuminating system, comprising dual projection lenses back to back to permit passage of parallel light from one to the other, and having said viewing zone at the focal point of the first projection lens and having an exit aperture at the focal point of the second projection lens, and a photomultiplier tube behind said exit aperture, standardizing means positioned in said viewing zone, said means comprising a fine polished wire positioned in said zone and including means for rapidly moving said wire through said zone to provide a light scattering surface in simulation of an aerosol particle, said light scattering serving to supply a constant optical impulse in the system to serve as a basis for standardizing the functioning of the elements of the system, electronic means in connection with said photomultiplier tube, said electronic means comprising tandem channel amplifiers having fixed gain, level detectors associated with each amplifier, an anti-coincidence circuit associated with each of two adjacent level detectors, each of said anti-coincidence circuits being in turn associated with a numerical register, said level detectors serving to sample the magnitude of the signal before and after each amplifier and to pass on a second signal whenever the sampled signal exceeds a given value preset for each level detector, said second signals passing to the anti-coincidence circuits, the second signals from the level detectors before and after a tandem amplifier, passing to a common anti-

coincidence circuit, said anti-coincidence circuit serving to pass on a third signal to the numerical register whenever the anti-coincidence circuit receives the second signal from only one level detector.

4. A system in accordance with claim 1, wherein the diluter comprises outer and inner concentric tubes with a transverse wall supporting the inner tube and interrupting the annular space between the tubes, said inner tube having a knife edge at one end and having an internal outward flare from said knife edge toward the opposite end of said tube.

5. A system in accordance with claim 1 wherein the diluter comprises outer and inner concentric tubes with a transverse wall supporting the inner tube and interrupting the annular space between the tubes, said inner tube having a knife edge at one end and said outer tube having an inner constriction beyond the end of the inner tube opposite the knife edge.

6. A system in accordance with claim 2, wherein there are twelve tandem channel amplifiers and wherein the input signal first passes through a preamplifier whereupon it enters the first channel amplifier and simultaneously passes into an auxiliary amplifier and then into the fifth channel amplifier, the auxiliary amplifier having the same gain as the first four tandem channel amplifiers in series.

7. A system in accordance with claim 1 wherein said optical means for illuminating a viewing zone comprises in series a light source, a condensing system, an aperture, dual projection lenses, positioned back to back to permit passage of parallel light from one to the other, which in turn permits independent focusing of the two projection lenses, and having said aperture at the focal point of the first projection lens, and having an illuminated viewing zone at the focal point of the second projection lens.

8. A system in accordance with claim 1 wherein said optical detecting means comprises dual projection lens positioned back to back to permit passage of parallel light from one to the other, and having the said viewing zone at the focal point of the first projection lens and having an exit aperture at the focal point of the second projection lens, and a photomultiplier tube positioned behind said exit aperture.

9. A system in accordance with claim 1, wherein said optical illuminating system comprises in series, a light source, a condensing system, an aperture, dual projection lenses, positioned back to back to permit passage of parallel light from one to the other, and having said aperture at the focal point of the first projection lens, and having an illuminated viewing zone at the focal point of the second projection lens, an optical viewing system positioned at an angle with said illuminating system,

comprising dual projection lenses back to back to permit passage of parallel light from one to the other, and having said viewing zone at the focal point of the first projection lens and having an exit aperture at the focal point of the second projection lens, and a photomultiplier tube behind said exit aperture.

10. A system in accordance with claim 1 wherein said optical means comprises a first optical system having in axial alignment a light source, a condensing system for projecting an image of the light source on an aperture, a projection lens positioned behind said aperture to include the said aperture at its focal point, a second projecting lens positioned adjacent said first projection lens to receive essentially parallel light from said first projection lens and serving to form an image of the aperture at its focal point, thereby constituting a viewing zone, a second optical system having an axis positioned at an angle to the axis of said first optical system comprising dual projection lenses positioned back to back to thereby pass essentially parallel light from the one to the other, said viewing zone being at the focal point of the first projection lens and an exit aperture at the focal point of the second projection lens, and a photomultiplier tube positioned behind said exit aperture.

11. A system in accordance with claim 10, wherein said light source is an incandescent, tungsten ribbon light bulb, said ribbon having an area at least as large as the aperture to be illuminated.

12. A system in accordance with claim 10, wherein angularly disposed light absorbing dark glass surfaces are positioned on the axis of the illuminating optical system behind said viewing zone and on the axis of the detecting optical system behind said viewing zone, light traps being positioned adjacent said light absorbing dark glass surfaces to receive and dissipate any remaining light reflected from said surfaces.

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