

Sept. 13, 1938.

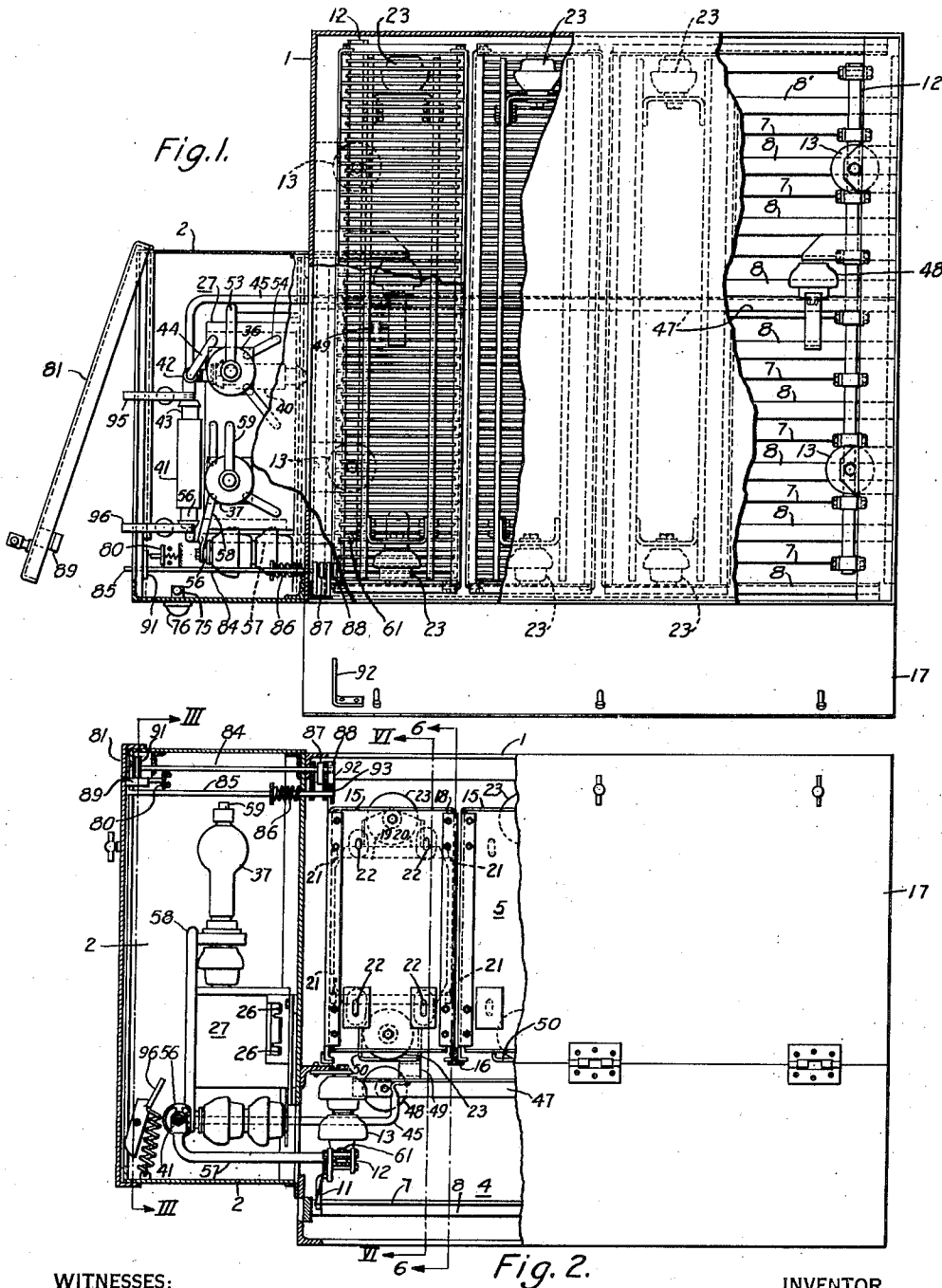
G. W. PENNEY

2,129,783

ELECTRICAL PRECIPITATOR FOR ATMOSPHERIC DUST

Filed Oct. 15, 1935

3 Sheets-Sheet 1



WITNESSES:

Wm. C. Groom
Wm. C. Groom

INVENTOR
Gaylord W. Penney
BY *O. B. Buchanan*
ATTORNEY

Sept. 13, 1938.

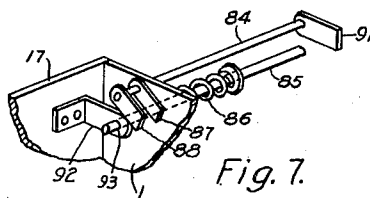
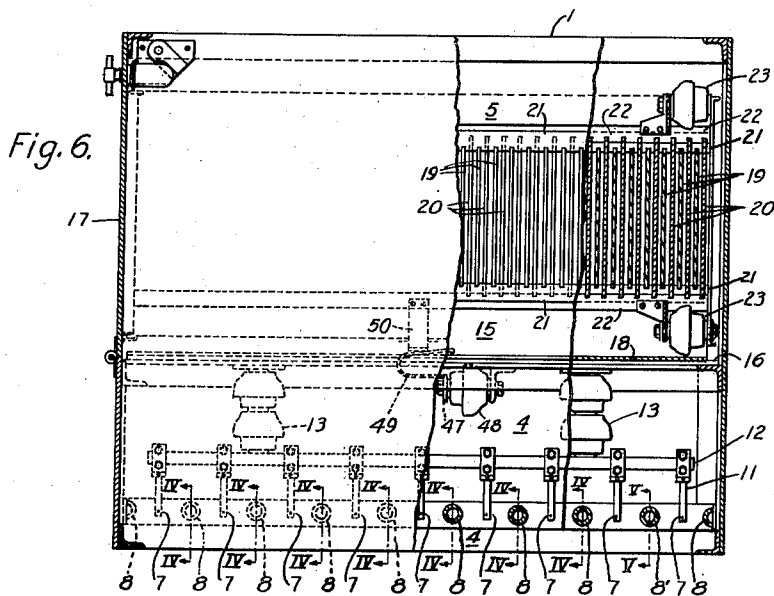
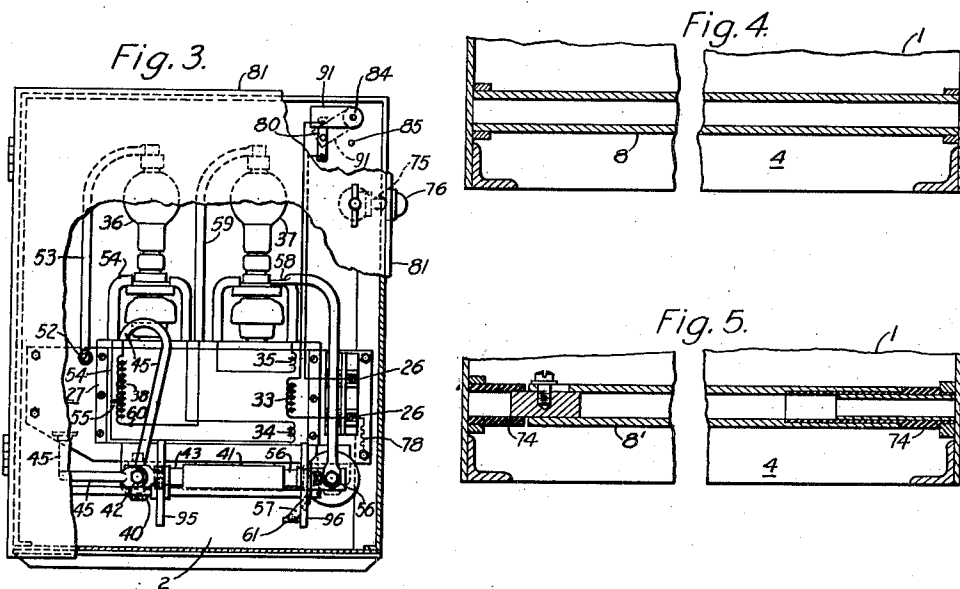
G. W. PENNEY

2,129,783

ELECTRICAL PRECIPITATOR FOR ATMOSPHERIC DUST

Filed Oct. 15, 1935

3 Sheets-Sheet 2



WITNESSES:
Fred. C. Witham
Wm. C. Groom

INVENTOR
Gaylord W. Penney
BY *O. B. Buchanan*
ATTORNEY

Sept. 13, 1938.

G. W. PENNEY

2,129,783

ELECTRICAL PRECIPITATOR FOR ATMOSPHERIC DUST

Filed Oct. 15, 1935

3 Sheets-Sheet 3

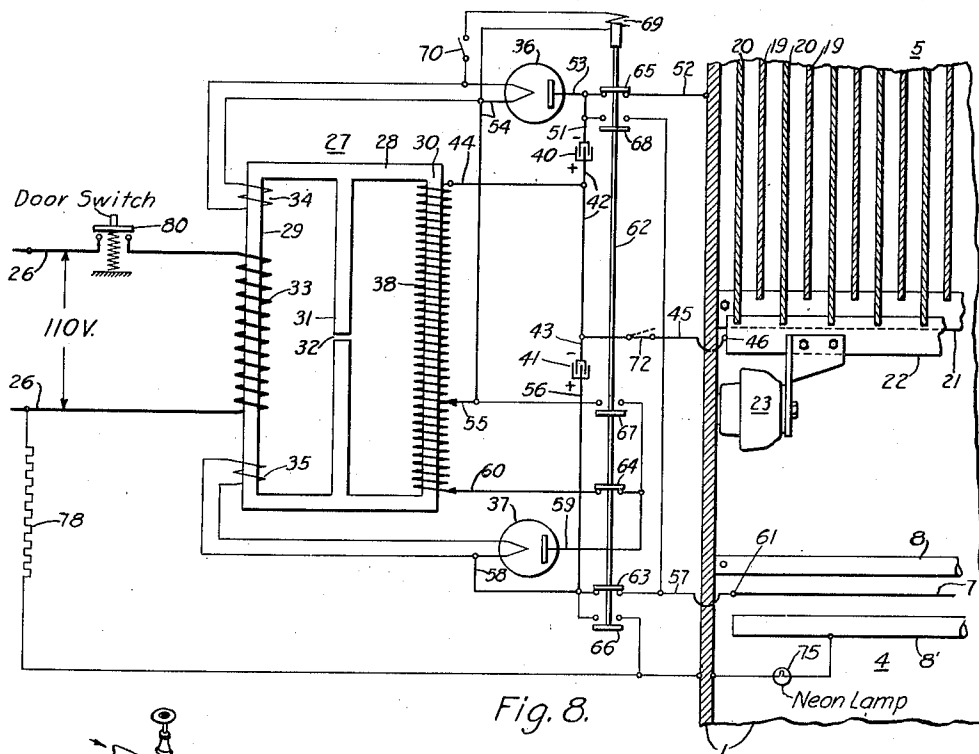


Fig. 8.

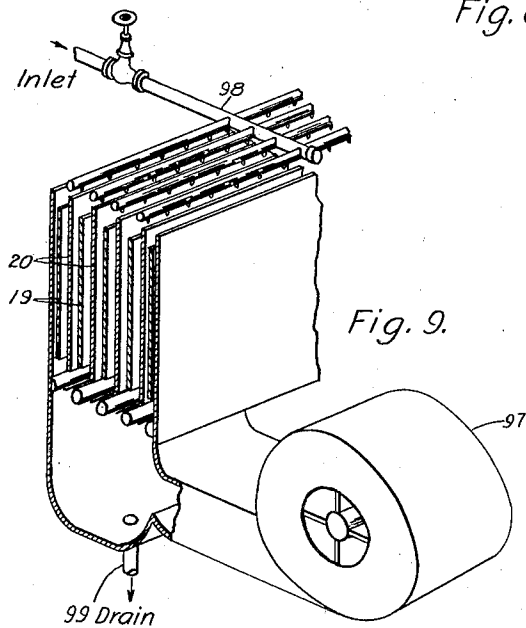


Fig. 9.

WITNESSES:

Fred. C. McNamee
Wm. C. Groome

INVENTOR

Gaylord W. Penney

BY *O. B. Buchanan*

ATTORNEY

UNITED STATES PATENT OFFICE

2,129,783

ELECTRICAL PRECIPITATOR FOR ATMOSPHERIC DUST

Gaylord W. Penney, Pittsburgh, Pa., assignor to Westinghouse Electric & Manufacturing Company, East Pittsburgh, Pa., a corporation of Pennsylvania

Application October 15, 1935, Serial No. 45,070

16 Claims. (Cl. 183-7)

My invention relates to electrical precipitators for atmospheric dust, and particularly, although not necessarily, such precipitators as may be used for the conditioning of air which is to be breathed.

The principal object of my invention is to achieve the cleansing of air without the production of more than traces of ozones or nitrous oxides, which are now known to be toxic and harmful when they are present in any material quantity in the air which is breathed.

Mechanical filters, for removing dirt or dust-particles, and particularly smoke-particles, from air, present certain difficulties, when limited to any practical air-pressure drop in the apparatus. These smoke-particles may be as small as .3 micron or less in diameter, that is, smaller than the wave-length of light. In cities, much of the dirt in the air is in the form of such smoke-particles. My invention is not limited as to the size of particles which it can precipitate, and it is thus well suited for the difficult task of precipitating dust from the air in, or supplied to, rooms or other places in which people live, particularly in cities, vehicles or the like, where smoke is present, as well as air-cleaning for industrial plants and processes.

The ordinary Cottrell precipitator, consisting of a single chamber for both ionizing and precipitating the foreign particles from the air, by means of a charged wire in a chimney, or other similar arrangement, cannot be used for comfort air-conditioning because of the large quantities of ozone and nitrous oxides that are generated.

An important feature of my invention is to design a precipitating apparatus which will operate efficiently, even more so than the Cottrell system, and yet in such manner that the ozone and nitrous oxides, if present at all, will be in such small quantities as to have no possible harmful effects, and in fact, so small as to be undetectable. Particularly, I keep the ozone-concentration down to a mere trace, and then it will necessarily follow that the nitrous-oxide problem ceases to exist. To this end, I separate the functions of ionizing the air (and thus charging the dust-particles) and precipitating the charged particles, utilizing separate chambers for these two functions.

It has heretofore been proposed, as in the patents to Schmidt, No. 1,343,285, patented June 15, 1920 and Möller, No. 1,357,466, patented November 2, 1920, to more or less separate the functions of ionization and precipitation in two separate chambers, but the ionization was not ac-

complished in such a way as to limit the discharge-current in the ionizing chamber. In fact, the patentees instructed those practicing their inventions that the ionization was produced by discharging electricity into the gas to be treated, and warned them to be certain to have a sufficiently high rate of discharge. This means that large quantities of ozone and nitrous oxides were produced.

An important feature of my invention in its preferred form, although I am not limited thereto, is that I utilize positive ionization, rather than the customary negative ionization; that is, my wire in the ionizing chamber is positive with respect to the walls of the chamber. In the Cottrell precipitating system, which has been the standard practice for many years, it has been necessary to utilize as high a voltage as possible, on the wire, in order to obtain an electrostatic field at the walls of the chamber, which is sufficiently strong to precipitate the charged foreign particles from the air. Particles could be ionized either positively or negatively with equal facility, and could be precipitated with equal facility once they were formed, but the flashover voltage between the wire and the walls of the ionizing chamber is considerably lower when the wire is positive than when the wire is negative. Hence, in the precipitating systems heretofore utilized, in which as much voltage as possible was applied to the wire, it has long been standard practice to make the wire negative.

My invention does not utilize an ionizing voltage anywhere approaching the flashover voltage, because very excessive ozone-production is encountered, long before the flashover point is reached. It is possible, therefore, for me to utilize either positive or negative ionization, and I have made the important discovery that, for a given current-flow, and hence for a given effectiveness of ionization, at least at the small current-inputs and physical dimensions which I utilize, the amount of ozone generated is substantially ten times as much, with negative ionization, as with positive ionization, or, for a given rate of ozone generation, positive ionization enables me to utilize higher voltages such as will produce a current-input substantially ten times as great as is possible with negative ionization. Thus, by utilizing a positively charged ionizing wire, I precipitate the dirt just as effectively as if I had utilized a negatively charged wire, and at the same time I achieve a much smaller space for the ionizing chamber than if negative ionization had been utilized, or I can

cause the dust particles to take on a much larger electrical charge in the ionizing chamber, with positive ionization, than with negative ionization, in the same size of chamber, thus causing the precipitation to be much more perfect in the precipitating chamber, or making it possible to utilize a smaller size of precipitating chamber or a higher velocity of air-flow for a given percentage of dust- or smoke-removal.

A still further improvement which I have introduced relates to the design of the ionizing chamber. Instead of utilizing a tubular ionizing chamber, or instead of utilizing an ionizing wire which is disposed longitudinally with respect to the direction of air-flow, with flat electrodes parallel to the direction of air-flow on either side of the ionizing wire, to constitute the walls of the ionizing chamber, I have found it significantly advantageous to utilize rounded-surface electrodes on either side of the ionizing wire, and to dispose the wire transversely with respect to the direction of the air-flow. In this way, I am able to obtain a significantly higher charging of the ionized particles, for a given rate of ozone-generation. I believe that this advantage is due to the intensity of the field through which the air passes, in the ionizing chamber, particularly in the portion of the ionizing chamber close to the outer walls or electrodes, that is, furthest away from the wire. I have found that, with an ionizing wire at the center of a rectangular ionizing chamber, with the air passing at right angles to the ionizing wire, the dust particles in the air passing through the region near the ionizing wire were much more effectively ionized than those passing outside, near the walls of the ionizing chamber. By utilizing curved-surface electrodes or pipes for the outside walls of the ionizing chamber, I have found that this deficiency in ionization near the outer walls is in large measure overcome, so that more efficient ionization is obtained.

With the foregoing objects in view, and others which will become apparent as the description proceeds, my invention consists in the systems, methods, apparatus, and combinations herein-after described and claimed and illustrated in the accompanying drawings, wherein:

Figure 1 is a top plan view of one form of embodiment of my precipitator, with parts broken away to show the construction;

Fig. 2 is a front elevational view of the same, also with parts broken away;

Fig. 3 is a sectional end view of the power-pack, the section being indicated by the line III—III of Fig. 2;

Fig. 4 is a sectional view on any one of the seven lines IV—IV of Fig. 6;

Fig. 5 is a sectional view on the line V—V of Fig. 6;

Fig. 6 is an end view of the precipitator cabinet proper, with parts broken away to show sections on lines 6—6 and VI—VI of Fig. 2;

Fig. 7 is a perspective view showing the details of a door interlock;

Fig. 8 is a diagrammatic view showing the electrical circuits; and

Fig. 9 is a somewhat diagrammatic perspective view of the entire assembly, including the blower and the plate-washing equipment, as well as the precipitator cabinet proper.

As shown in Figs. 1 and 2, the main portions of my invention are disposed in two cabinets, the larger of which is the precipitator cabinet 1, on the side of which is mounted, as an appendage, a

smaller power-pack cabinet 2, both cabinets being illustrated as being made of aluminum, although they may be of other metallic or non-metallic construction. The precipitator cabinet 1 is open at its bottom for the entrance of the air to be conditioned. The lower portion of the cabinet 1 contains the ionizing chamber 4, which really, in the illustrated embodiment, consists of a plurality of ionizing chambers arranged side-by-side. The upper portion of the cabinet 1 contains the precipitating chamber 5, which really, in the illustrated embodiment, consists of a plurality of precipitating chambers arranged side-by-side. The cabinet 1 is open, at the top, for the discharge of the conditioned air. A small amount of uni-directional high-voltage power, for the charging of the electrical parts of the ionizing and precipitator chambers, is converted in the power-pack cabinet 2, which is mounted on the side of the main cabinet 1.

The ionizing chamber 4 is shown in Figs. 1, 2 and 6. It is shown as comprising nine parallel, spaced ionizing wires 7, which, according to my invention, should preferably be very fine wires. It will usually be found advantageous to make the wires 7 as small as considerations of mechanical strength will permit. In the particular design illustrated, the wires 7 are tungsten wires of 6 mils diameter. My experiments, however, have included wires as small as .6 mil in diameter and as large as 32 mils in diameter. The ionizing wires 7 are arranged in a horizontal plane, substantially at right angles to the direction of air-flow, which is upwardly through the cabinet. Each ionizing wire is mounted in the center of an ionizing unit of the ionizing chamber 4. The use of a single wire in each ionizing unit assures that, within the effective range of its electrostatic field, the wire itself will determine and control the maximum potential-gradient which occurs at the surface of the wire, thus contributing materially to the creation of a high gradient at the wire-surface, unimpaired by other electrodes at the wire-potential within the effective range of the field surrounding said wire, or, what amounts to the same thing, within each ionizing unit. The side-walls of each ionizing unit, according to a preferred form of embodiment of my invention, are composed of the opposing surfaces of spaced cylindrical electrodes 8 which may consist of aluminum tubes grounded on the framework of the cabinet. These ionizing units are disposed transverse to the direction of air-flow in the cabinet, that is, in such a manner that the air flows in a general cross-wise direction across the wires and between the pairs of cylindrical electrodes 8.

The grounded tubular electrodes 8, which constitute the side-walls of the ionizing chamber or chambers 4, are about one inch in diameter in the particular embodiment of my invention illustrated in the drawings. As previously intimated, I believe it to be desirable for these tubes to be fairly small, so as to increase the intensity of the electrostatic fields between each tube and its associated ionizing wires 7, but the diameter must not be so small as to produce anything like the extremely high voltage-gradient which is obtained in the region immediately surrounding the fine wire 7, in which ionization by collision occurs. The tubes 8, therefore, should be very large, as compared to the fine wires 7.

The ionizing wires 7 are suspended, at each end, from brackets 11 depending from a trans-

versely disposed bar 12, which is supported by two insulators 13.

Each of the four precipitator chambers 5 is formed by a unitary collector-cell assembly 15, as shown in Figs. 1, 2 and 6. These collector-cell assemblies are constructed somewhat like drawers which can be easily and quickly slid in and out, on supporting beams 16 constituting slides. The cabinet is provided with a door 17, through which these collector-cell assemblies may be removed, if such removal should become necessary for ordinary cleaning purposes, or for emergency cleaning because of contamination with some unusual obstruction, or for any other cause.

Each collector cell 15 of the precipitating chamber 5 consists of a metallic framework 18, which is grounded on the supporting slides 16 which constitute a part of the metallic framework of the cabinet 1. Each collector cell contains a large number of vertical plates 19 and 20, alternating with each other, with a separation of something like one-fourth of an inch, or usually not much more than one-half inch apart, for the most economical utilization of space, as will be subsequently pointed out. The plates 19 are grounded plates, supported by notched bars 21 which are carried by the grounded framework 18 of the collector cell. The plates 20 are insulated plates carried by notched bars 22, which are supported by insulators 23.

A very small amount of electrical energy is utilized for charging the insulated ionizing wires 7 and the insulated precipitator plates 20. This power is furnished by my power-pack 2, which is shown in Figs. 1, 2 and 3, the electrical connections of which are indicated in Fig. 8. Relatively low-voltage energy, such as may be obtained from an ordinary 110-volt lighting circuit, enters the power-pack through low voltage leads 26, as shown in Figs. 3 and 8. This energy is fed into a transformer 27, which consists of a magnetizable core 28 (Fig. 8) consisting of a primary leg 29, a secondary leg 30, and an intermediate leg 31 having an air-gap 32 therein constituting a leakage path for the flux, whereby the amount of energy which may be withdrawn from the transformer is distinctly limited. The primary leg 29 carries a primary winding 33, which is connected to the low-voltage input leads 26. The primary leg 29 also carries two tertiary windings 34 and 35 for the excitation of the filaments of two rectifier tubes 36 and 37. The transformer leg 30 carries a secondary winding 38 which produces a high voltage for application to the plate-circuits of the rectifiers 36 and 37.

In order to reduce the voltage which must be handled by each one of the rectifier tubes, I utilize an arrangement whereby the voltage of the secondary winding 38 may be multiplied, by means of two energy-storing devices 40 and 41, each of which is arranged to receive the unidirectional energy-output of its associated tube 36 and 37, respectively, to constitute a substantially constant source of voltage even during the non-conducting periods of the respective rectifiers. Because of the extremely small amount of high-voltage charging-current required for my apparatus, which is of the order of a milliamper, more or less, the two energy-storing devices 40 and 41 may conveniently be small capacitors, as illustrated. The two capacitors 40 and 41 are connected in series, with their potentials adding, that is, with the positive terminal 42 of the capacitor 40 connected to the negative terminal 43 of the capacitor 41. These two terminals are

also connected to one terminal 44 of the secondary winding 38, and to a lead 45 for energizing the insulated plates 20 of the precipitator chamber.

The connection between the lead 45 and the insulated plates 20 is indicated schematically at 46 in Fig. 8, but in Figs. 1, 2 and 6, the detailed construction is shown. The lead 45 extends from the power-pack into the main cabinet 1, where it is bolted onto a horizontal insulated bar 47 which is disposed between the ionizing chamber 4 and the precipitating chamber 5, being supported on insulators 48. The bar 47 carries four spring-contact members 49 which are adapted to make electrical contact with metallic contact-brackets 50, depending from the insulated plate-supporting bars 22 of each of the four collector cells or precipitator-chamber units 15.

Referring again to the details of the power-pack shown in Figs. 1, 2, 3 and 8, it will be observed that the negative terminal 51 of the capacitor 40 is grounded on the casing, as indicated at 52, and is also connected to the anode terminal 53 of the rectifier 36. The cathode terminal 54 of said rectifier 36 is connected to an intermediate tap 55 on the secondary winding 38. The positive terminal 56 of the capacitor 41 is connected to a terminal-lead 57 which charges the ionizing wires 7, and is also connected to a cathode lead 58 of the rectifier 37. The anode lead 59 of said rectifier 37 is connected to the other terminal 60 of the secondary winding 38.

The electrical connection between the terminal-lead 57 and the ionizing wires 7 is indicated diagrammatically at 61 in Fig. 8. The details of the connection are shown in Figs. 1, 2 and 3, which show that the lead 56 extends into the main cabinet 1, where it is bolted, at 61, onto one of the insulated bars 12 which supports one end of the wires 7.

The connections just described are the connections which I prefer at present, being the ones which are utilized in the apparatus shown in Figs. 1, 2 and 3. According to my invention, however, it is possible to use either negative or positive ionization, the only difference being that, with negative ionization, the voltage on the wires must be very greatly reduced, until the current-input on the wires becomes only one-tenth of its former value, for the same amount of ozone-production, thus materially reducing the amount of charging of the dust particles, and rendering the precipitation much less perfect; or else requiring a material reduction in the velocity of air-flow through the apparatus.

It is possible, however, that as our knowledge of the qualities which give the invigorating effect to pure outside air becomes more fully known, it may be found desirable to alternate between positive and negative ionization, in order to control the positive- and negative-ion content of the conditioned air; or it may be found desirable to dispense altogether with either positive or negative ionization, or to utilize one form of ionization at times, and the other form at other times. To date, the researches on the subject of ionization of air appear to me to be indicative that no discernible physiological or psychological effects may be attributed to any reasonable amount of concentration of either positive or negative ions in the air.

In order, however, to enable the user of my precipitating equipment to conduct his own experiments in the matter, or to satisfy his own whims or future scientific findings as to ionization, I have shown the wiring diagram in Fig. 8

as including an electromagnetic change-over switch 62 having three normally closed or "break" contacts 63, 64 and 65, and three normally open or "make" contacts 66, 67 and 68. The electromagnetic switch 62 is actuated by means of an energizing coil 69 which is actuated from any convenient source, such as the low-voltage transformer-winding 34, through any suitable controlling switch 70, either manual or automatic. When the change-over switch 62 is actuated by the closure of the controlling switch 70, the contact 63 breaks the connection between the cathode lead 58 of the rectifier 37 and the terminal-lead 57 which is connected to the ionizing wires 7; and the contact 66 establishes a connection between said cathode lead 58 and the casing of the cabinet 1, which is grounded. At the same time, the contacts 64 and 67 transfer the connection of the anode lead 59 of the rectifier 37 from the transformer terminal 60 to the intermediate tap 55. At the same time, the contact 65 breaks the connection between the negative terminal 51 of the capacitor 40 and the ground-lead 52; and the contact 68 establishes a connection between said negative terminal 51 and the terminal-lead 57 of the ionizing wires 7.

I have also shown means for interrupting the precipitator function of my apparatus, so as to make it possible to operate the apparatus, at times, with an increased amount of ionization of the air leaving the apparatus. To this end, as shown in Fig. 8, I provide a switching means 72, either manual or automatic, in the lead 45 for energizing the insulated plates 20 of the precipitator chamber. My novel ionizing chamber 4 may thus be utilized to operate as a source of ionization for the conditioned air, either separately, or in conjunction with other air-conditioning equipment (not shown) for treating the air either for living purposes or for controlling commercial processes.

Suitable means are also provided for indicating when the apparatus is in need of cleaning. When this occurs, the precipitator plates 19 and 20 are short-circuited, and the high-leakage transformer 27 reduces the transformer secondary voltage by shifting the transformer flux from the secondary leg 30 to the leakage leg 31, thereby very greatly reducing the voltage on both the precipitator plates 20 and the ionizing wires 7. In order to conveniently indicate when this effect occurs, one of the tubular electrodes 8 which cooperates with the ionizing wires 7 is insulated, as indicated at 74 in Fig. 5, the insulated tube 8 being designated by a primed numeral 8', the remaining tubes 8 being grounded on the framework of the cabinet, as shown in Fig. 4. The insulated tube 8' is connected to the casing of the cabinet through a small glow lamp 75, which is shown in Fig. 8, said glow lamp being conveniently mounted on the front of the power-pack 2, so as to shine through a bull's-eye glass 76, as shown in Fig. 3. When the secondary circuit of the transformer 27 is short-circuited, the glow lamp 75 ceases to glow, and indicates the necessity for cleaning the apparatus.

Frequently it is desirable to have some means of grounding the case without having to run a separate wire to a water-pipe, or anything of that sort. In the apparatus as shown in Figs. 3 and 8, I accomplish this by connecting the case to one side of the 110-volt circuit 26 through a resistor 78 of approximately one megohm resistance. This will carry off any high-voltage charge tending to be induced in the case by the high-voltage

parts therein. Theoretically it might be possible to get 110 volts off of the cabinet. However the current that is available through the megohm resistor 78, which is like a poor insulator, is so small that it cannot be felt, or give a shock, and no ordinary voltmeter can measure it.

Suitable means are also provided for preventing the opening of either the main precipitator cabinet 1 or the power-pack cabinet 2 when power is being supplied to the transformer 27. To this end, there is included, in the primary circuit of the transformer, a door-switch 80, as shown in Fig. 8. This door-switch is conveniently mounted in the power-pack cabinet 2, to be opened by the opening of the door 81 of the power-pack cabinet, as shown in Figs. 1, 2 and 3. Thus, the entire electrical supply is interrupted whenever the power-cabinet door 81 is open.

I have also shown interlocking means between the main-cabinet door 17 and the power-pack door 81, so that the former may not be opened except when the latter is closed, and the latter may not be closed unless the former is also closed. To this end I have shown, by way of illustration, two rods 84 and 85 extending between the two cabinets as shown in Fig. 2. The upper rod 84 is rotatable through a slight arc, while the lower rod 85 is slidable longitudinally for a short distance, being normally pressed outwardly, so that it prevents closure of the power-pack door 81, by means of a spring 86.

The rotatably mounted rod 84 carries, on its inner end, that is, the end extending within the main cabinet 1, two gravity-biased arms or dogs 87 and 88 which are fixed on the rod 84, and which tend to fall down into such position that the arm 87 lies back of the inner end of the sliding rod 85 and prevents the same from being pushed inwardly against the action of its biasing spring 86. In this position, the rod 85 projects out far enough in front of the power-pack to prevent the door 81 from closing tight enough to close door-switch 80. The door 81 carries a projection 89 which makes contact with the door-switch 80 and closes the same when the door is fully closed.

The rotating bar 84 also carries, on its front end, an arm or dog 91 which comes down over the front of the door-switch 80, when the rotating bar 84 is in its gravity-actuated position, just described. In this manner, the arm 91 prevents the closure of the door-switch 80 by reason of an accidental contact of the hand or any other object therewith, while the power-pack door 81 is open.

The rotatable bar 84 is moved from its biased position by the main-cabinet door 17, which has an arm or projection 92 mounted on its inner surface, so that, when the door is closed, the projection 92 strikes against the depending arm 88 and rocks the same backwardly, thereby moving the arm 87 from behind the inner end of the sliding rod 85, and also moving the arm 91 from in front of the door-switch 80 in the power-pack. The sliding rod 85 is thereupon free to be pressed inwardly against the biasing action of its spring 86, and when the power-pack door 81 is closed, an inward movement of the sliding bar 85 is effected, causing the inner end of the same to engage within a perforation 93 in the projection 92 attached to the main-cabinet door 17, thereby locking the latter against opening. The closure of the power-pack door also brings the projection 89 thereof into contact with the door-switch 80 and closes the same, thereby establishing the primary circuit of the power-pack transformer 27

as soon as the primary terminals or leads 26 are plugged into a suitable source of supply, such as an alternating-current house-lighting circuit.

As a further safeguarding means, and as a means for quickly discharging the capacitors 40 and 41, I have also shown, by way of example, two spring-biased short-circuiting members 95 and 96 carried by the power-pack, and grounding the positive terminals 42 and 56, respectively, of the two capacitors 40 and 41, when the power-pack door 81 is open. Closure of the door 81 pushes the grounded switches 95 and 96 away, out of contact with the positive terminals of the capacitors.

The complete assembly of my device, in a form of embodiment suitable for use in factories, or in the basement of a house, for air-conditioning the entire house, is shown in Fig. 9. Air is forced through cabinet by means of a centrifugal blower 97, which is intended to be symbolic of any means, including "natural" or "gravity" circulation, for producing or causing the air-flow through the cabinet. Means are also provided for washing the plates 19 and 20, as by means of a sprayer or sprinkler system 98 mounted thereabove, so that water may be sprayed thereon to wash off the dirt, which is carried away through a suitable drain 99.

In operation, if the wires 7 are charged positively with respect to the grounded tubular electrodes or walls 8 of the ionizing chamber 4, the potential gradient immediately surrounding the wires is considerably greater than the critical gradient for ionization-by-collision in air at atmospheric pressure, which is of the order of 30 or 31 kilovolts per centimeter. While the ionizing voltage is far below the sparkover voltage or spitting point, at which corona which is visible in sunlight appears around the wires, which may be referred to as the critical corona voltage, the voltage which I utilize on the wires produces a discharge or corona which is distinctly visible in a dark room, in the immediate vicinity of the wires.

The regions immediately surrounding the wires have the highest voltage-gradient, in which ionization-by-collision occurs, while the regions near the walls of the ionizing chamber, that is, near the tubular electrodes 8, have a lower voltage-gradient which, in my device, is so low that I obtain a very low velocity of ion-drift, and hence a very limited current-flow in the ionizing chamber 4. The limited extent of the tubular electrodes 8 in the vertical direction, that is, in the direction of air-flow, and the sharp falling off of the electrode-surface away from the wires 7, due to the curvature of the tubular electrodes 8, undoubtedly also has a great deal to do with the limitation of the number of ions or charged particles reaching the electrodes 8, thus assisting materially in securing the aforesaid limited current-flow in the ionizing chamber.

The ionization-by-collision occurs within a short radius from the wires 7. While I am not limited to any particular radius of this region of ionization, I believe that this region extends, in my apparatus, for something like some 10 to 40 mils from the wires. In this region, both negative and positive ions are produced, but the negative ions or electrons are immediately drawn to the wire and neutralized by the positive charge on the wire. The positive ions travel toward the negative tubular electrodes 8, but the gradient applied to these ions quickly decreases, as their distance from the wire increases, so that their drift-

velocity becomes quite low, thus providing time during which the thermal movement of the ions causes them to become attached to dust-particles, thus charging or ionizing the dust-particles. The mass of the dust-particle is so large, as compared to the mass of a positive ion, that those positive ions which become attached to dust-particles practically cease to continue to drift toward the negative tubular electrodes 8.

While a reduced field in the vicinity of the negative tubular electrodes 8 is desired, both on account of the reduced velocity of ion-drift, and the necessity for avoiding ionization-by-collision at the tubular electrodes 8, I have found it desirable not to reduce the potential-gradient to too small a value, at the negative tubular electrodes 8, as I have found that much more effective ionization or charging of the dust-particles is secured when the negative or grounded electrodes 8 are tubular, rather than plane surfaces parallel to the direction of air-flow. I attribute this result to the fact that the intensity of the field has a considerable effect upon the acquisition of a charge by a dust-particle; that is, it is evidently better to have the opposite surfaces of the dust-particle at as high a potential apart as is practicable to be obtained without producing ionization-by-collision at the grounded tubular electrodes 8.

I have not determined the exact limits of the permissible sizes or diameters of the tubular electrodes 8, but I have reason to believe that satisfactory operation may be obtained over a wide range of diameters. The tubes which are utilized in the embodiment of my invention shown in the drawings are approximately of one-inch diameter, and are spaced 4 inches between centers, or 3 inches between the surfaces of the tubes, which means an inch and a half between each wire and the nearest surface of the adjacent tube 8.

The amount of ozone generated in the ionizing chamber is dependent, among other things, upon the amount of current-input, and also upon the potential, of the ionizing wire. Thus, with negative ionization, a current-input of one micro-ampere per cubic foot per minute of air-flow is about the upper limit of current-input which can be utilized without producing objectionable ozone-concentration, this current-input producing about one part of ozone in from 50,000,000 to 75,000,000 cubic feet of air, at a ratio of about 500 or 1000 to 1 between the spacing between the surfaces of the tubular electrodes 8 and the diameter of the ionizing wire 7. The corresponding power-limit, in the ionizing chamber, is about .01 watt per cubic foot per minute of air-flow. With positive ionization, the corresponding limits are about 10 times as great, or about 10 micro-amperes per cubic foot per minute, or .1 watt per cubic foot per minute.

Excessive quantities of ozone are objectionable because many materials, such as rubber, will soon fall to pieces, when exposed to ozone, and because of a definite ozone smell which is observed with concentrations as high as one part in about 50,000,000, and which is objected to by some people. An ozone-concentration of more than one part in 10,000,000 is distinctly undesirable. In still higher concentrations, ozone produces headaches, and the doctors use the term "lethal" in describing its effects. While there is some disagreement as to the effect of ozone, I believe that it is generally accepted that a little ozone is desirable. Air which is confined in a room quickly

loses its ozone, which is apparently converted into ordinary oxygen or oxygen compounds. Fresh pure mountain air is known to have an ozone concentration of about one part in 100,000,000 or even one part in 10,000,000; and it is quite probable that this ozone-content contributes to the "live" or "fresh" feeling of the air, as distinguished from the seemingly lifeless air which is circulated in buildings or caves away from the outside air or sunlight.

For most applications, the current and wattage input into my ionizing chamber must be kept much below the limits which I have indicated. I usually use such a low current-input as to generate only one part of ozone, or less, in some 300,000,000 parts of air. In recirculating ventilating systems, where the air of the building is recirculated over and over again, with small additions of outside air, it is necessary to take care that the rate of ozone-generation in my precipitator-apparatus does not exceed the rate at which the ozone dissipates itself in the recirculating system of the building, as otherwise a cumulative increase in ozone-content will be encountered, which will soon bring about a very objectionable concentration of ozone in the building.

Ozone concentrations of the order of one part in from 100,000,000 to 300,000,000 parts of air are too small to be accurately analyzed chemically, by any means which we know now. The only way that we know it is there, is by making a test at reduced air-flow, but with the same rate of ozone-generation, so as to get a measurable quantity of ozone. The method which I have utilized for determining the amount of ozone is described in "Untersuchungen über Ozone", by Wartenberg and Podjaski, in Zeitschrift für anorganische und allgemeine Chemie, vol. 148, pages 391-396, October 29, 1925. When I speak of ozone-concentrations, therefore, I mean concentrations as determined by this method. The ozone analyses are very difficult, and it is extremely hard to obtain results which are in any degree consistent with each other. The figures which have been given for the ozone-concentrations must be taken, therefore, with very wide allowance for differences in test-results.

The important thing about my invention is that it affords a means for precipitating dust or foreign particles from air without generating intolerable quantities of ozone, thus rendering the electrostatic precipitating process available as a means for dust or dirt removal in general air-conditioning operations, as a substitute for the much less effective, previously used air washers and air filters, and as a means for producing conditioned air having a "fresher" feeling than air which is cleaned by other processes. I obtain this reduction in ozone-generation by utilizing current and wattage-inputs well below the limits which I have indicated, and by utilizing a separate precipitator chamber in which I obtain the precipitation or withdrawal of the charged or electrified dust-particles from the air.

There are other factors which affect the rate of ozone-generation, other than current- or wattage-input and polarity of ionization in the ionizing chamber. Other things being equal, the smaller the wire, the smaller the amount of ozone generated. For example, in one test, a wire of 32 mils diameter gave about twice the ozone per unit of current as a wire of 8 mils diameter in the same apparatus. The wire which is utilized in the apparatus shown in the drawings is of 6 mils diameter, and it is very much larger than it really

needs to be, for successful commercial use, this wire having been made large enough to be able to withstand exceedingly rough handling and use in experimental equipment. Much finer wires have been tested by me, the smallest being of about .6 mil diameter. It is advantageous to have the wire as small as considerations of mechanical strength will permit.

I prefer to utilize an ionizing wire 7 which is small and essentially smooth on its outer surface. I prefer this to a barbed wire, or wire with roughenings or protuberances on its surface, in which case the effective diameter of the wire is considerably increased by the presence of the barbs or protuberances, and as above indicated, I prefer a wire as small as is conveniently practicable.

For a given wire-size, a given current, and a given potential of ionization, the rate of ozone-generation is reduced by making the ionizing chamber larger, that is, by increasing the distance between the surfaces of the tubular electrodes 8, but, of course, any increase in the size of this chamber, or in the spacing between the tubular electrodes 8, will require a considerable increase in voltage in order to maintain the same current. In my apparatus, with the limitations with which I have been confronted in the voltage-ratings of available rectifier tubes 36 and 37, I have found it desirable to design the ionizing chamber for the highest voltage which was economically obtainable by the tubes, and to then adjust the spacings of the tubes 8 so as to obtain as high a current-input as considerations of ozone-generation would permit.

The ratio between the distance between the surfaces of the tubular electrodes 8 and the diameter of the ionizing wires 7 should thus, in general, be as high as is practicable. This ratio should preferably be not less than that which is obtained in my illustrated apparatus, which is about 500 to 1, although ratios as low as about 100 to 1, or even lower, might still be utilized, in some instances. It is advantageous, however, to use much higher ratios, such as 2000 to 1, or higher. The dust-particles, in passing through the ionization chamber 4, take on an electrical charge dependent upon the number of positive ions which become attached to them. In any event, this electrical charge is much smaller than that which is given to the dust-particles in the ordinary Cottrell precipitator wherein enormous quantities of ozone are also produced. In order to precipitate the relatively weakly ionized dust-particles which are obtained in my ionizing chamber, the air is next passed through the precipitator chamber 5 wherein the separation of the ionized particles from the air is performed in the spaces between parallel plates 19 and 20, where the electrostatic field is substantially uniform and hence can be maintained at a relatively high value, so that dust-particles which are even slightly ionized can be effectively precipitated. The ionizing and precipitating chambers 4 and 5, while performing different functions, merge one into the other, with no separating means of any kind therebetween.

The spacing between the plates 19 and 20 of the collector cell assembly or precipitator chamber should be as small as considerations of short-circuit difficulties will permit. I have found that, with the larger plate spacings, the effects of accumulations of dirt-particles, in producing point-discharges, is more noticeable, so that, as the plate-spacing is increased, the voltage cannot be increased at as rapid a rate as the plate spacing, so that the wider spacings of the plates require

apparatus which is somewhat larger in size than apparatus having the smaller plate spacings. One limit which is encountered as to the closeness with which the plates may be spaced is the impossibility of obtaining commercial plates which are sufficiently flat. For instance, commercial plates 8 inches square will usually vary from $\frac{1}{64}$ inch to $\frac{1}{4}$ inch, from being perfectly flat. There is a range in plate-spacing, from about $\frac{1}{16}$ inch or $\frac{1}{8}$ inch, up to $\frac{1}{2}$ inch, or even considerably larger, that might be commercial. The plate-spacing in the design which is shown in my drawings is approximately .22 inch, but this plate-spacing may be very considerably reduced, with some resulting economies in the size of the equipment, or it might be considerably increased if there was no particular necessity for reducing the size of the precipitator.

The length of the plates 19 and 20, in the direction of air-flow, must be sufficiently high, in consideration of the sizes and charges of the dust-particles and the intensity of the electrostatic field between the plates, to withdraw substantially all of the dust-particles from the air, or any desired percentage thereof, such as 95%, or 99½%, before the air passes out of the precipitator chamber. This is determined by the velocity of drift of the charged dust-particles under the influence of the electrostatic field, and the maximum distance of drift, which is the distance between adjacent plates. The air-velocity must be so chosen that the air is not blown out of the precipitator before the dust-particles have had time to drift over onto the negative plates.

There is also an upper limit of air-velocity, which is the velocity at which the dust is blown off from the plates unless the plates are coated with oil or other adhesive material. For most kinds of dirt, this limiting velocity is more than 800 feet per minute, but it is conceivable that in some instances the dirt may be of such nature that it will blow off at even 400 feet per minute.

In the design shown in my drawings, I utilize about 14,000 volts on the ionizing wires 7, giving an average voltage-gradient of 14,000/1.5 or 9,300 volts per inch in the ionizing space, and about 4500 volts on the charged plates 20, giving an average voltage-gradient of 4500/.22 or 20,500 volts per inch in the precipitating space, although, as will be understood from the foregoing discussion, I am by no means limited to these particular values. The voltage on the plates could advantageously be very considerably increased, the only objection to such increase being an occasional flashover or spitting within the plate structure, due to the presence of an insect or piece of straw or lint in the precipitating chamber, which does no harm, due to the limited current-output of the transformer 27, because the insect or other foreign matter is quickly destroyed by a single spark or flash, after which the voltage is instantly restored and the apparatus operates as usual. Obviously, such large foreign particles may be excluded by suitable screening (not shown).

The plates of the precipitator chamber will have to be cleaned at intervals varying from possibly a few hours, for artificial dust in commercial operations, up to six months for cleaning typical Pittsburgh city air in summer. This time might be stated as of the order of one week or two months, depending upon the time of the year and the location of the city. Some kinds of dirt can be removed by jarring the plates, or can be blown off with a jet of compressed air. For simplicity of illustration, I have shown my inven-

tion with a washing system for washing off the dirt by means of a water sprayer or sprinkler, thus avoiding the necessity for removing the plates in order to clean them. By reason of the high leakage construction of the transformer 27, it is quite possible to wash the plates while the transformer is energized, as the transformer will limit the short-circuit current, which would result from the washing, to a value which will not harm the tubes or other apparatus; or, if desired, the set may be momentarily shut down during the washing process.

If a negative ionization is utilized, as by the closure of the switch 70 in Fig. 8, the process will be the same, except that the ionization of the dust-particles will be negative, and will have to be carried out at a somewhat lower voltage, as has been indicated by showing the connections for the capacitor 41 so that said capacitor is energized across the transformer-taps 40—53 instead of across the transformer-terminals 40—60. The dust-particles will then be precipitated, in the precipitator chamber, by being drawn over to the positive plates.

While I have described my invention in a preferred form of embodiment, and have suggested certain limits in accordance with my best understanding of the same at the present time, I desire it to be distinctly understood that I am not altogether limited to these limits or understandings, or to the particular form of embodiment shown in the drawings. I desire, therefore, that the appended claims shall be accorded the broadest construction consistent with their language and the prior art.

I claim as my invention:

1. An air-purifying precipitator comprising a metal supporting-frame, an ionizing chamber, a separate precipitator chamber, and means for causing an air-flow successively therethrough; said ionizing chamber comprising one or more insulatedly supported fine wires spaced between substantially uninsulatedly supported, relatively large electrodes; said precipitator chamber comprising a plurality of insulatedly supported, spaced, substantially parallel plate-electrodes, substantially parallel to the direction of air-flow, and a plurality of substantially uninsulatedly supported, spaced, substantially parallel plate-electrodes interspersed with said insulated plate-electrodes and spaced therefrom; a plurality of relatively low-voltage power-supply leads for feeding electric energy into the precipitator; voltage-conversion, relatively high-voltage means for unidirectionally charging said fine wire or wires and said insulated plate electrodes relatively to said substantially uninsulated parts; and a resistor for grounding said frame and said substantially uninsulated parts onto one of said low-voltage leads, said resistor having a resistance sufficiently large to prevent a shock from said low-voltage power-supply, but sufficiently small to dissipate any substantial charge tending to be induced in said frame from said high-voltage parts.

2. A gas-purifying precipitator comprising an ionizing chamber, a separate precipitator chamber, and means for causing a gas-flow successively therethrough; said ionizing chamber comprising one or more insulatedly supported fine wires spaced between substantially uninsulated, relatively large electrodes; said precipitator chamber comprising a plurality of alternately insulated and uninsulated, substantially uniformly spaced, precipitating electrodes, substantially

parallel to the direction of gas flow; a plurality of relatively low-voltage power-supply leads for feeding electric energy into the precipitator; and limited-energy, voltage-conversion, relatively high-voltage means for unidirectionally charging said fine wire or wires and said insulated precipitating electrodes relatively to said substantially uninsulated parts, said limited-energy means having such a limited wattage-output that it will withstand a short-circuit on said relatively high-voltage parts.

3. The invention as specified in claim 2, characterized by the fine wires being of less than 32 mils diameter, the wire-charging voltage being below the critical corona voltage.

4. The invention as specified in claim 2, characterized by the fine wires being of less than 32 mils diameter, the unidirectional charging voltages being such that the potential-gradient in the spaces between said plates is in excess of the average gradient in the ionizing space.

5. An air-purifying precipitator as defined in claim 2, characterized by the fine wires being of less than 32 mils diameter, the wires being charged positively with respect to said relatively large electrodes, and the wire-charging voltage, the wire-diameter and the ratio of the wire-diameter to the spacing between the large electrodes being all sufficiently small and so proportioned that the current-input in the ionizing chamber is so small that the quantity of ozone generated is substantially undetectable by ordinary methods, at the concentration in which it is present in the treated air leaving the precipitator.

6. An air-purifying precipitator as defined in claim 2, characterized by the fine wires being of less than 32 mils diameter, the wires being charged positively with respect to said relatively large electrodes, and the wire-charging voltage, the wire-diameter and the ratio of the wire-diameter to the spacing between the large electrodes being all too small to cause enough current-input in the ionizing chamber to produce, in the treated air, an ozone-concentration objectionable for breathing purposes.

7. A gas-purifying precipitator comprising an ionizing chamber, a separate precipitator chamber, and means for causing a gas-flow successively through first said ionizing chamber and then said precipitator chamber; said ionizing chamber being provided with one or more ionizing units, each unit being disposed transverse to the gas-flow and comprising a pair of parallel relatively large electrodes and a single insulatedly supported relatively small electrode disposed between the pair of large electrodes, the relatively small electrode being a fine wire of less than 32 mils diameter, the relatively large electrodes being of limited extent in the direction of gas-flow and having an effective surface having a radius of curvature which is large at all points of said effective surface as compared to the radius of curvature of the fine wire, and means for unidirectionally charging said fine wire relative to said large electrodes, whereby foreign particles in the air are charged by the fine wire; said precipitator chamber comprising a plurality of parallel plates spaced more closely than the spacing between said fine wire

and either of its associated relatively large electrodes, and means for unidirectionally charging said plates to alternate positive and negative potentials such that the potential-gradient in the spaces between said plates is in excess of the average gradient in the ionizing space.

8. The invention as defined in claim 7, characterized by the wire-charging voltage being below the critical corona voltage.

9. An air-purifying precipitator as defined in claim 7, characterized by the wire-charging voltage being so low that there is but a relatively small current-flow, a substantially undetectable amount of ozone-generation, and no important amount of precipitation in the ionizing chamber.

10. An air-purifying precipitator as defined in claim 7, characterized by the wire-charging voltage, the wire-diameter, the ratio of the wire-diameter to the spacing between the large electrodes, and the limited extent of the large electrodes, being all sufficiently small and so proportioned that the current-input in the ionizing chamber is so small that the quantity of ozone generated is substantially undetectable by ordinary methods, at the concentration in which it is present in the treated air leaving the precipitator.

11. An air-purifying precipitator as defined in claim 7, characterized by the wire-charging voltage, the wire-diameter, the ratio of the wire-diameter to the spacing between the large electrodes, and the limited extent of the large electrodes, being all too small to cause enough current-input in the ionizing chamber to produce, in the treated air, an ozone-concentration objectionable for breathing purposes.

12. The invention as defined in claim 7, characterized by said fine wire being charged positively with respect to said large electrodes.

13. The invention as defined in claim 7, characterized by said fine wire being charged positively with respect to said large electrodes, and the wire-charging voltage being so low that the current-input in the ionizing chamber is of the order of 10 micro-amperes, or less, per cubic foot of gas treated per minute.

14. The invention as defined in claim 7, characterized by said fine wire being charged positively with respect to said large electrodes, and the wire-charging voltage being so low that the power-input into the ionizing chamber is somewhat less than 0.1 watt per cubic foot of gas treated per minute.

15. The invention as defined in claim 7, characterized by said fine wire being charged negatively with respect to said large electrodes, and the wire-charging voltage being so low that the current-input in the ionizing chamber is of the order of 1 micro-ampere, or less, per cubic foot of gas treated per minute.

16. The invention as defined in claim 7, characterized by said fine wire being charged negatively with respect to said large electrodes, and the wire-charging voltage being so low that the power-input into the ionizing chamber is somewhat less than 0.01 watt per cubic foot of gas treated per minute.

GAYLORD W. PENNEY.