# United States Patent [19]

**Rork et al.**

[11] **3,735,138**

[45] **May 22, 1973**


[54] **IONIZATION SMOKE DETECTOR**


[75] Inventors: **Gerald D. Rork**, Bloomington, Minn.; **Alfred S. Schlachter**, Paris, France; **Frank N. Simon**, Bloomington; **Robert A. Stryk**, Edina, both of Minn.

[73] Assignee: **Honeywell Inc.**, Minneapolis, Minn.



[22] Filed: **Oct. 27, 1971**

[21] Appl. No.: **192,827**

[52] **U.S. Cl.**..........**250/83.6 FT**, 235/151.35, 250/44

[51] **Int. Cl.**..............................................**G01t 1/18**

[58] **Field of Search**.........................250/44, 83.6 FT; 235/151.35


[56] **References Cited**

UNITED STATES PATENTS


| | | | |
|---|---|---|---|
| 3,448,261 | 6/1969 | Amiragoff | 250/83.6 FT X |
| 3,521,263 | 7/1970 | Lampart et al | 250/83.6 FT X |



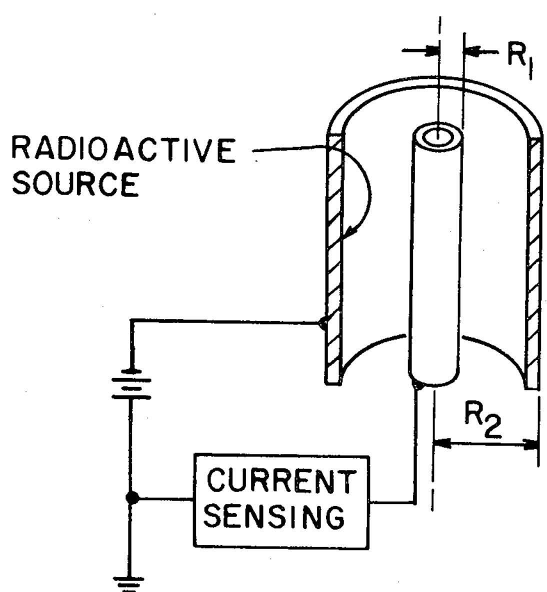
*Primary Examiner*—Archie R. Borchelt

*Attorney*—Lamont B. Koontz and Omund R. Dahle


[57] **ABSTRACT**


An improved ionization type smoke detector which is specifically designed to be independent of variations in atmospheric pressure and to be highly sensitive to smoke. A number of factors are involved in choosing optimum design parameters for an ionization smoke detector which has minimum sensitivity to pressure and which also has a maximum sensitivity to the presence of smoke. Several equations are described which aid in the design.


**2 Claims, 6 Drawing Figures**



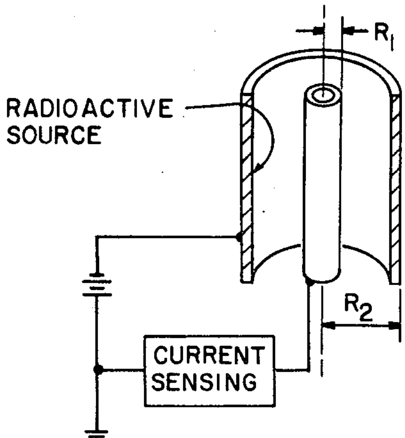



FIG. 1

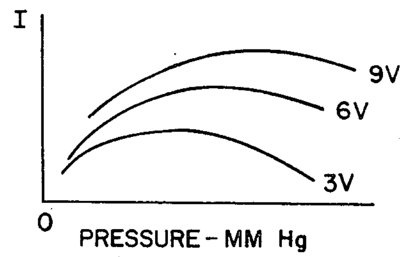



FIG. 2

CHANGE IN I FOR CHANGE IN MOBILITY

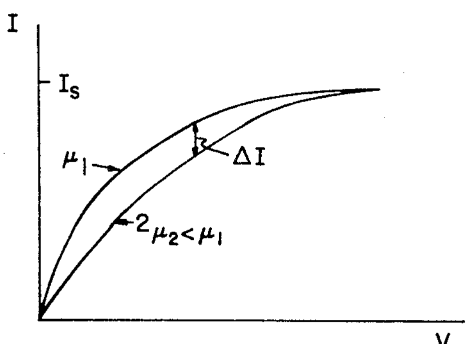
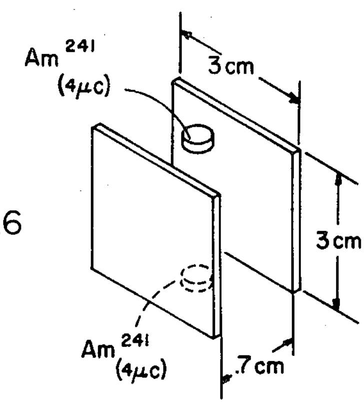



FIG. 3

FIG. 6




DETECTOR SENSITIVITY TO MOBILITY CHANGE

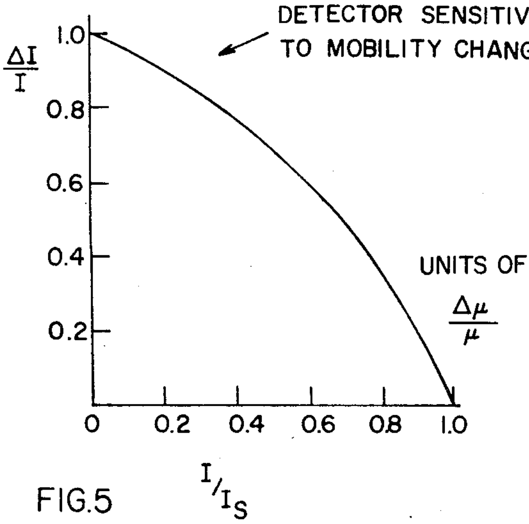



FIG. 5

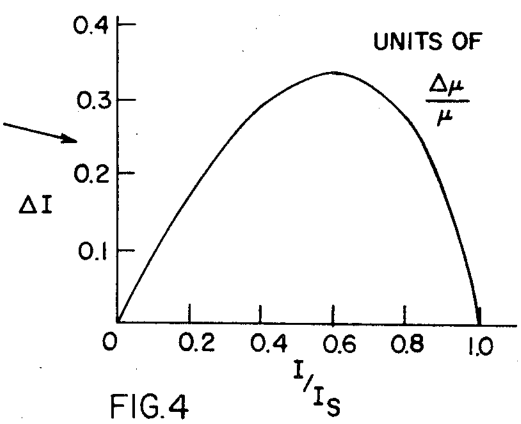



FIG. 4

*INVENTOR.*
GERALD D. RORK
ALFRED S. SCHLACHTER
FRANK N. SIMON
ROBERT A. STRYK

# IONIZATION SMOKE DETECTOR

## BACKGROUND AND SUMMARY OF THE INVENTION

The present invention is directed to an improved ionization type products-of-combustion, or smoke detector in which the baseline current is essentially independent of variations in atmospheric pressure near one atmosphere (760 mm Hg) that is, over the pressure range of about 600–800mm Hg. The ionization type smoke detector consists of a radioactive ionization source, electrodes across which a voltage is applied and ionization current flows and electronic circuitry for measuring the current flow between the electrodes.

## BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a diagrammatic representation and partial cross-section of an embodiment of an ionization smoke detector of the type described.

FIG. 2 is a graphic example of change in current for a change in pressure of the smoke detector with voltage as a parameter.

FIG. 3 is a graphic display of change in current for change in ion mobility at fixed voltage.

FIGS. 4 and 5 are a graphic display of the Detector Sensitivity to Mobility change as a function of $I/I_s$.

FIG. 6 is a diagrammatic representation of an embodiment having a parallel plate geometry evolved from one solution of the mathematical relationships explained below.

## DETAILED DESCRIPTION

Ionization type smoke detectors, in general, operate on the following principles: Primary particles (high energy electrons called $\beta$ particles, from $Ni^{63}$ for example or high energy helium nuclei called $\alpha$ particles, from $Am^{241}$ for example) are randomly emitted from a radioactive source. These, in turn, collide with air molecules and other vapors with sufficient energy to ionize them forming positive and negative ion pairs. Each primary particle ionizes a large number of air molecules in its path. This number for air at ordinary pressure is given to a sufficient degree of accuracy by $N = E/30$, where $E$ is the source energy in electron volts. For example, $\beta$ particles from $Ni^{63}$ have an average energy of about 18,000 electron volts. For this energy,

$N = (18 \times 10^3)/30 \approx 600$ ion pairs/emitter particle.

The number of primary particles emitted per second from a source is called its activity measured in curies. One millicurie (mC) of $Ni^{63}$ produces $3.7 \times 10^7$ primaries per second. Therefore, 1 mC of $Ni^{63}$ yields

600 (ion pairs/primary) $\times\ 3.7 \times 10^7$ (Prim./Sec.) = $22 \times 10^9$ (ion prs./sec.)

This number is the so called generation rate of current in an ionization cell. If these ions are collected at the electrodes at the same rate as they are generated, the current in our $Ni^{63}$ example

$I_s = 22 \times 10^9$ (ions prs./sec.) $\times\ 1.6 \times 10^{-19}$ (coulombs/ion) $= 35.2 \times 10^{-10}$ or 3520 picoamps.

$I_s$ is the saturation current that occurs when the voltage on the cell is raised high enough to collect all the ions produced. The curves of FIG. 3 show current plotted against voltage and the saturation current is clearly apparent from the curves as voltage increases. We have found the radioactive intensity needed for pressure independence in this invention, whether it be generated by an alpha or a beta source, is one capable of producing a rate of ion pair production equivalent to a saturation current in the range of about 450 to about 650 picoamperes.



## PRESSURE INDEPENDENCE

As the air pressure in the cell is increased, the number of ion pairs $N$ generated per primary particle increases, since more air molecules are struck and ionized by each primary before it strikes the cell wall and expends the rest of its energy there. $I_s$ increases with pressure until a pressure is attained which dissipates essentially all the energy of the primary particles whereupon further increases in $I_s$ with P do not occur. This condition that $I_s$ increases with pressure in the desired pressure operating range ($\approx$700 mm Hg) cooperates with another condition to achieve pressure independence of the measured operating current. The curves of FIG. 2 show this increase of current with increase in air pressure.

A first optimizing feature of this invention is that the cell is normally operated at a current level (I) below the saturation level ($I_s$). Under this condition of operation, only a fraction of the ion pairs generated are collected. The remainder simply recombine to form neutral molecules again. It may be said that in the steady state, the total number generated per second equals the number collected per second plus the number combining per second. The recombination rate depends among other things on a characteristic of the ion called its "mobility" which is a measure of the speed that the ion moves in the electric field. The mobility is different for different vapors, as is shown in FIG. 3, and so the rate at which ions recombine differs for different vapors. The mobility is also pressure dependent, that is, the higher the pressure the lower the effective mobility, and since this means larger recombination the collected current is smaller. Thus higher pressures tend to give smaller currents because of the mobility decrease, while higher pressures tend to give larger currents because of the saturation current increase. These two opposing effects are adjusted to be equal and opposite such that pressure changes no longer affect the current, by choosing the proper geometry and operating current. The proper operating current I to accomplish this is given by an equation,

$$I = I_s - (P_o/2)\ (dI_s/dP)\ P_o \tag{1}$$

where

$I_s$ = saturation current

$(dI_s/dP)\ P_o$ = change in saturation current with change in pressure

$P_o$ = desired operating pressure (about 700 mm Hg).

It is desirable, of course, to use cell dimensions, saturation current $I_s$, and operating current $I$ given by Equation 1 to get pressure independence and at the same time obtain a very sensitive response to smoke. In other words, the relative sensitivity ($\Delta I/I$), that is, the ratio of the change in current (called $\Delta I$) when smoke is present to the static operating current $I$ should be high. A further feature of the optimization work is that we have found an additional mathematical relation which specifies the cell dimensions so that operating the cell at current $I$ given by Equation 1 will also provide the maximum $\Delta I/I$ for optimum sensitivity. This latter equation is somewhat involved since the geometry factor occurs implicitly. However, graphical solutions show it is possible to select the factor for any desired ΔI/I value, and any specified operating voltage V.

The attainment of an optimized set of parameters for ionization cells by purely empirical methods is difficult because of the large number of complex physical processes involved in any ionization phenomena. We have approached optimizing the parameters by quantitative methods, ascertaining at each step that the theoretical results and predictions agree with experimental measurements. The first step is the determination of the importance of space charge effects on the predicted voltage-current relationship for a variety of simple geometries. We determined that space charge is relevant only in scaling the particular geometry used. We thus derived a relation that depended on recombination and generation rates that was shown to predict $I$ vs. V once a geometry was specified. This result is given by Equation 2.

$$I = AV^2\mu^2 \left[ \sqrt{(2\, I_s/AV^2\mu^2) + 1} - 1 \right] \tag{2}$$

where

$A$ = geometry factor

Examples of $A$ for parallel plate geometry and concentric cylinders are given below.

$A = qlw/2kd^3$ parallel

$A = (16\ \pi\ q)/(k\ [R_2^2 - R_1^{\ 2}]\ [\ln\ (R_2/R_1)\ ])^{\ 2}$ concentric cylinders

$q$ = electron charge

$k$ = recombination coefficient

$d$ = interelectrode spacing

$l$ = length

$w$ = width

$R_2$ = outer radius

$R_1$ = inner radius

$\mu$ = average mobility

$I_s$ = saturation current

$V$ = applied voltage

## SENSITIVITY

We can use Equation 2 to determine sensitivity of a detector as a function of choice of parameters. We can define sensitivity to be either total or fractional change in current for a change in ion mobility, i.e., $\Delta I$ or $\Delta I/I$ for a given $\Delta\mu/\mu$. This change in $I$ is illustrated in FIG. 3 which shows $V$–$I$ curves for ions of two different mobilities.

To determine $\Delta I$ for a change in ion mobility, we differentiate Equation 2 with respect to $\mu$.

$$\Delta I = \frac{2\left[ I_s + A\mu^2V^2 - A\mu^2V^2 \sqrt{\frac{2I_s}{A\mu^2V^2}+1} \right]}{\mu\sqrt{\frac{2I_s}{A\mu^2V^2}+1}}$$

Equation 3

or $\Delta I/I = f\,[V, I_s, A](\Delta\mu/\mu)$

Consider if $V$ is eliminated between Equations 2 and 3, the sensitivity is expressible as a function of $I$, and $I_s$.

$$\Delta I = 2I\ [\ (I_s/I) - 1/2(I_s/I) - 1\ ]\ (\Delta\mu/\mu) \tag{4}$$

$$\Delta I/I = 2\ [(I_s/I) - 1/2(I_s/I) - 1\ ](\Delta\mu/\mu) \tag{5}$$

It is observed that the current I in Equation 2 is a function of various parameters; functionally we can write $I = f\,[A, \mu(P), I_s(P), V\,]$, where

$P$ = operating pressure

$V$ = operating voltage, and

$A$ = Geometry factor.

Three of these parameters may be adjusted arbitrarily within a restricted range (such as $I_s$, $I$ and $A$) to satisfy any reasonably conditions we wish to impose. We therefore specify

a. Pressure Independence or $(dI/dP)\ V = 0$

b. Sensitivity value or $(\Delta I/I)\ V = S_o$

c. An operating voltage $V = V_o$.

Condition (a) requires that

$$I = I_s - ½\ P_o\ (dI_s/dP)\ P_o \tag{1}$$

Condition (b) requires that $I_s$ be selected such that

$$S_o = 2\ (I_s - I/2I_s - I)\ (\Delta\mu_o/\mu_o) \tag{6}$$

where $(\Delta\mu_o/\mu_o)$ is the fractional mobility and/or volume or surface recombination change when a specified smoke level is admitted to the cell.

Condition (c) specifies a value for $A$, *the field geometry factor.*

Equations (1), (2) and (6) provide a consistent set of three equations which can be satisfied simultaneously by values of the three adjustable parameters $A$, $I$ and $I_s$ so that a high sensitivity consistent with pressure independence is achieved in any chosen design. These equations have solutions over certain physically realizable value ranges of the parameters. If the equations cannot be solved for the values as shown, then one of the specified items of sensitivity or operating voltage must be modified and the equations solved again. This leads to a restricted range of acceptable values for the parameters of sensitivity, operating voltage, saturation current, operating current and geometry.

In constructing a sensor according to the invention, the geometry may take the form of concentric cylinders, parallel plates, or other suitable geometry. For purposes of illustration, one successful embodiment of the invention is described in which a parallel plate geometry is used such as shown in FIG. 6. As indicated above, we may specify pressure independence, we may specify an arbitrary value of sensitivity such as $S_o$ =25 percent, and we may specify an arbitrary operating voltage such as $V_o$ = 5 volts. Solving equations 1, 2 and 6 provide numbers of $I$, $I_s$ and $A$ which satisfy the equations described for desired sensitivity and pressure independence and in which $I_s$ = 550 pa. and $I$ = 300 pa. for the saturation current and operating current respectively, and the dimensions of the rectangular parallel plates interelectrode spacing, and amount of radioactive material as shown in FIG. 6 satisfy the geometry factor to provide pressure insensitivity without sacrificing values of sensitivity and operating voltage.

The embodiments of the invention in which an exclusive property or right is claimed are defined as follows:

**1.** A single chamber pressure independent ionization type device for detecting products-of-combustion, the device being of the type where a unidirectional interelectrode current flows between a pair of electrodes and the occurrence of products-of-combustion causes a current change $I$, the improved device comprising:

a pair of electrodes having a geometrical factor $A$, which geometrical factor includes electrode spacing and electrode size,

a radioactive source having a radioactive intensity capable of producing a rate of ion pair production equivalent to a saturation current $I_s$ of about 450 to about 650 picoamperes,

voltage supply means providing an interelectrode operating current $I$ of about 200 to about 500 picoamperes, at an operating voltage $V$ and

said geometry factor $A$, saturation current $I_s$, operating current $I$, operating voltage $V$, and operating pressure $P$ being interrelated according to the relations

1. $I = I_s - (P_o/2)\ (dI_s/dp)\ P_o$
2. $I = AV^2\mu^2\ [\ \sqrt{(2I_s/AV^2\mu^2)+1} - 1\ ]$



3. $S_o = 2\ (I_s - 1/2I_s - 1)\ (\Delta\mu_o/\mu_o)$

thereby causing said operating current to be essentially independent to variations in pressure.

**2.** A method for designing a pressure independent ionization type products-of-combustion sensing device which, in addition to allowing the specifying of pressure independence, concurrently allows the specifying of arbitrary values of sensitivity and of operating voltage within a restricted range, the method comprising the steps of

a. specifying (1) pressure independence, (2) an arbitrary value of sensitivity, (3) and an arbitrary operating voltage;

b. substituting the specified values into the three simultaneous equations

1. $I = I_s - P_o/2\ (dI_s\ /dP)\ P_o$
2. $I = AV^2\ \mu^2\ [\ \sqrt{(2I_s/AV^2\ \mu^2)+1} - 1\ ]$
3. $S_o = 2\ (I_s - 1/2I_s - 1)\ (\Delta\mu_o\ /\mu_o)$

c. Solving the above three simultaneous equations to derive values of saturation current $I_s$, operating current $I$ and geometry $A$;

d. utilizing the derived values and the specified operating voltage in the design of the device.

* * * * *

# UNITED STATES PATENT OFFICE
# CERTIFICATE OF CORRECTION

PATENT NO. : 3,735,138

DATED : May 22, 1973

INVENTOR(S) : Gerald D. Rork, Alfred S. Schlachter, Frank N. Simon and Robert A. Stryk

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 2, line 47, cancel "$I = I_s - (P_o/2)(dI_s/dP)P_o$" and substitute --$I = I_s - \frac{P_o}{2}\left(\frac{dI_s}{dP}\right)_{P_o}$ --.

Column 2, line 53, cancel "$(dI_s/dP)P_o$" and substitute --$\left(\frac{dI_s}{dP}\right)_{P_o}$ --.

Column 4, line 1, cancel "$\Delta I = 2I[(I_s/I) - 1/2(I_s/I) - 1](\Delta\mu/\mu)$" and substitute

$$--\Delta I = 2I\left[\frac{\frac{I_s}{I} - 1}{2\frac{I_s}{I} - 1}\right]\left(\frac{\Delta\mu}{\mu}\right)--.$$

Column 4, line 5, cancel "$\Delta I/I = 2[(I_s/I) - 1/2(I_s/I) - 1](\Delta\mu/\mu)$" and substitute

$$--\frac{\Delta I}{I} = 2\left[\frac{\frac{I_s}{I} - 1}{2\frac{I_s}{I} - 1}\right]\left(\frac{\Delta\mu}{\mu}\right)--.$$

Column 4, line 22, cancel "$I = I_s - 1/2P_o(dI_s/dP)P_o$" and substitute --$I = I_s - \frac{1P_o}{2}\left(\frac{dI_s}{dP}\right)_{P_o}$ --.

UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 3,735,138 Dated May 22, 1973

Inventor(s) Gerald D. Rork, Alfred S. Schlachter, Frank N. Simon and Robert A. Stryk

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 4, line 27, cancel "$S_o = 2(I_s - I/2I_s - I)(\Delta\mu_o/\mu_o)$" and substitute --$S_o = 2\left(\frac{I_s - I}{2I_s - I}\right)\left(\frac{\Delta\mu_o}{\mu_o}\right)$--.

Column 5, penultimate line, cancel "$I = I_s - (P_o/2)(dI_s/dP)P_o$" and substitute --$I = I_s - \frac{P_o}{2}\left(\frac{dI_s}{dP}\right)_{P_o}$--.

Column 6, line 1, cancel "$S_o = 2(I_s - 1/2I_s - 1)(\Delta\mu_o/\mu_o)$" and substitute --$S_o = 2\left(\frac{I_s - I}{2I_s - I}\right)\left(\frac{\Delta\mu_o}{\mu_o}\right)$--.

UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 3,735,138 Dated May 22, 1973

Inventor(s) Gerald D. Rork, Alfred S. Schlachter, Frank N. Simon and Robert A. Stryk

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 6, line 16, cancel "$I = I_s - P_o/2(dI_s/dP)P_o$" and substitute

$$--I = I_s - \frac{P_o}{2}\left(\frac{dI_s}{dP}\right)_{P_o} --.$$

Column 6, line 18, cancel "$S_o = 2(I_s - 1/2I_s - 1)(\Delta\mu_o/\mu_o)$" and substitute

$$--S_o = 2\left(\frac{I_s - I}{2I_s - I}\right)\left(\frac{\Delta\mu_o}{\mu_o}\right)--.$$

**Signed and Sealed this**

*Eleventh* **Day of** *April 1978*

[SEAL]

*Attest:*

RUTH C. MASON
*Attesting Officer*

LUTRELLE F. PARKER
*Acting Commissioner of Patents and Trademarks*