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GAS MIXTURES FOR SPARK GAP CLOSING SWITCHES WITH EMPHASIS ON EFFICIENCY OF OPERATION*

L. G. Christophorou,† D. L. McCorkle,† and S. R. Hunter

Atomic, Molecular, and High Voltage Physics Group
Health and Safety Research Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831

ABSTRACT

The efficient operation of a spark gap closing switch requires a gaseous medium with large breakdown strength, low conduction voltage, and a short formative time lag. Gas properties necessary to achieve these requirements are identified and discussed. Based on available knowledge of such properties, a number of binary (e.g., c-C_4F_8, or 1-C_3F_6, or n-C_4F_{10}, or C_3F_8, or C_6F_6 in Ar or He or H_2) and ternary gas mixtures (e.g., c-C_4F_8, or n-C_4F_{10}, or C_3F_8 in Ar or He + C_2H_2 or another low ionization onset additive) have been identified which may be suitable for use in spark gap closing switches.

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KEYWORDS

Gas mixtures, spark gaps, closing switches, efficiency.

INTRODUCTION

Spark gap closing switches are a crucial element of many advanced technologies such as high power lasers, pulsed power equipment, and particle accelerators (Woodworth *et al.*, 1982; Kimura *et al.*, 1986). High power switches such as those triggered by a triggertron or by laser photoionization are gas filled (usually at atmospheric or higher pressures). The role of the gas is to serve as a good insulator when the switch is open and as a good conductor when the switch is closed. There is a need for gaseous media with suitable properties to be used in spark gap closing switches in order to improve the efficiency, repetition rate, and recovery characteristics as well as the lifetime of such devices. In this paper we report on the basic physical properties of gaseous media needed to optimize such switches, especially for improving their efficiency. We also identify a number of gas mixtures which could be suitable for use in spark gap closing switches.

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†Also, Department of Physics, The University of Tennessee, Knoxville, Tennessee 37996.

PROPERTIES OF GAS MIXTURES NEEDED TO OPTIMIZE THE PERFORMANCE OF SPARK GAP CLOSING SWITCHES: CANDIDATE GAS MIXTURES

The time dependence of the voltage and current in a spark gap closing switch is as shown schematically in Fig. 1. The switch is initially open (nonconducting). In this stage the voltage, V_0, applied to the electrodes of the switch is high (close to the breakdown voltage, V_s). The density-reduced electric field, E/N, is high and the temperature of the gas is ambient during this stage. When the switch closes (becomes conducting) at time $t = \tau_0$, the voltage, V(t), drops and the current, i(t), increases. The transition from the opening to the conducting stage takes place within the time $\tau_c - \tau_o \simeq \tau_f$(≡ formative time lag) (Fig. 1.). The voltage V_c across the two electrodes during the conducting stage is much lower (by a factor of ~10) than V_o. The E/N is now low, and the gas temperature is high. It is highly desirable that such switches close quickly and at a minimum energy loss. In terms of the efficiency E_{ff} of the switch, it can be shown that a "figure of merit" expression is given approximately by

$$E_{ff} = (1 - V_c/V_o)^2 \quad .$$

Thus, to improve the efficiency of the switch, V_0 must be large (i.e., the breakdown strength or voltage, V_s, must be large), V_c must be small (i.e., resistivity low), and τ_f short.

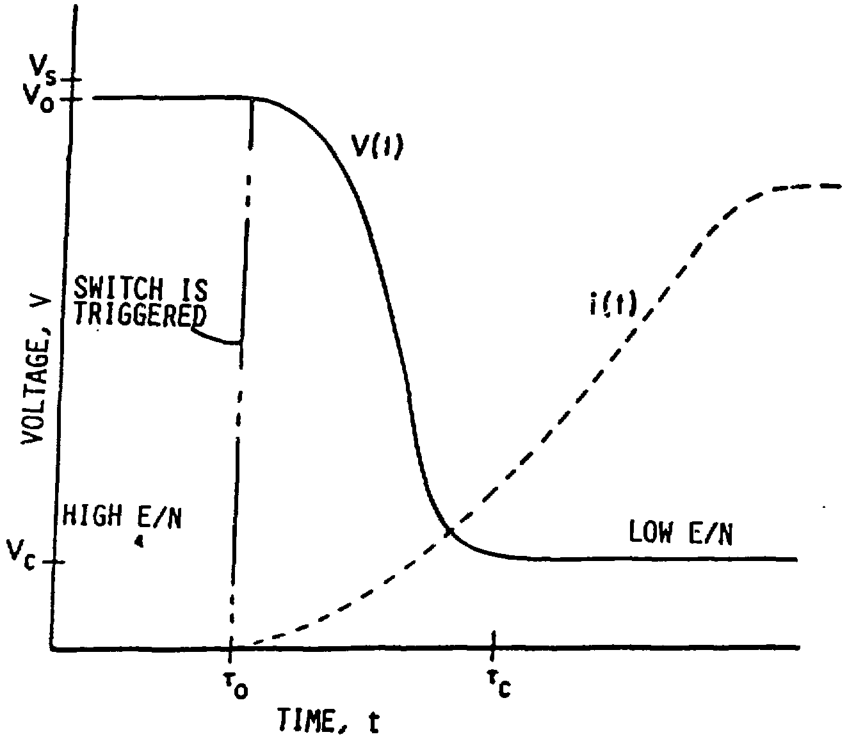

Fig. 1. Voltage, V(t), and current, i(t), versus time, t, in a spark gap closing switch ($\tau_c - \tau_0 \simeq \tau_f$ ≡ formative time lag).

In Table 1 we list the properties of a gas/mixture which are needed for the gas to optimize the performance of the switch. These fall into three groups:

a. *Those which optimize the operation of the switch in the initial, nonconducting stage.* Here the gas must have as high a V_s as possible. The critical molecular property is a large attachment rate constant $k_a(\langle\epsilon\rangle)$ [or cross section $\sigma_a(\epsilon)$] at room temperature extending to high mean electron energies $\langle\epsilon\rangle$. We have identified a number of gases possessing such attachment rate constants which also decrease as the temperature, T, increases (this property is needed for (b.) below). The attachment rate constants as a function of the mean electron energy at various T of these gases[1] are shown in Figs. 2, 3, 4, and 5. The dielectric strength of these gases is large, equal to or in excess of that of sulfur hexafluoride (Christophorou and Hunter, 1984).

TABLE 1 Properties of a Gaseous Medium Needed to Optimize the Performance of a Spark Gap Closing Switch

- **Large V_0**
  - large k_a $(\langle\epsilon\rangle)$ or $\sigma_a(\epsilon)$, especially at high E/N
  - large k_a $(\langle\epsilon\rangle)$ or $\sigma_a(\epsilon)$ at low T
  - large electron scattering cross section at subionization energies
- **Small V_c:** large conductivity/low resistivity; low E/N
  - high electron drift velocity w at low E/N; maxima in conductivity versus E/N
  - no electron attachment at low E/N
  - strong electron attachment at low T and weak or no electron attachment at high T
  - large rate of ionization
- **Short τ_f**
  - large change in $\bar{\alpha}/N$ with E/N around $(E/N)_{\ell im}$ (the steeper the increase of $\bar{\alpha}/N$ with E/N the better, because the lower would be the τ_f and, consequently, the faster the transition to the arc)

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[1] Other polyatomic molecules can be found whose k_a $(\langle\epsilon\rangle)$ behave similarly. These must attach electrons nondissociatively at low energies. If, however, in addition, in the low energy range such molecules attach electrons dissociatively, the k_a $(\langle\epsilon\rangle)$ not only may not decrease but it may actually increase with T. This is because, as a rule, k_a $(\langle\epsilon\rangle)$ decreases with increasing T when electron attachment leads to parent anions and increases when electron attachment leads to fragment anions (Christophorou *et al.*, 1987).

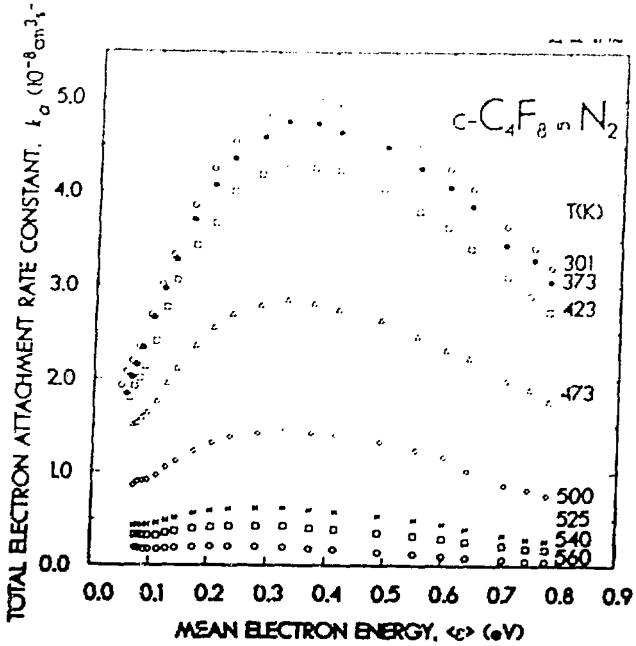

Fig. 2. k_a (<ε>, T) versus <ε> for c-C$_4$F$_8$ (perfluorocyclobutane) (Christodoulides *et al.*, 1987).

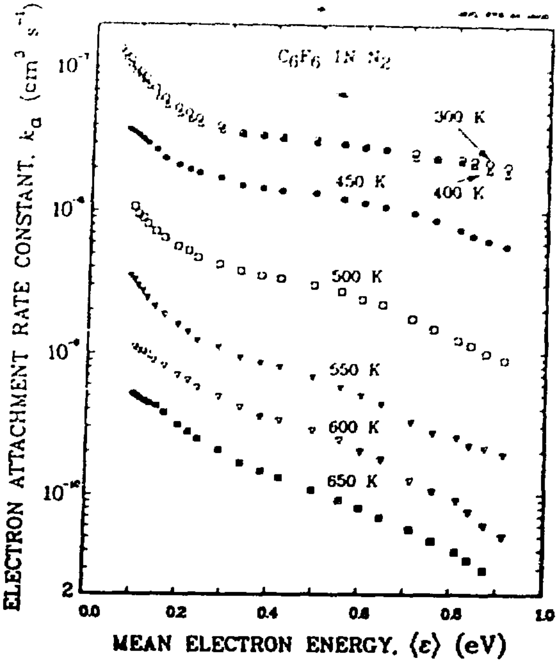

Fig. 3. k_a (<ε>, T) versus <ε> for C$_6$F$_6$ (hexafluorobenzene) (Spyrou and Christophorou, 1985 a).

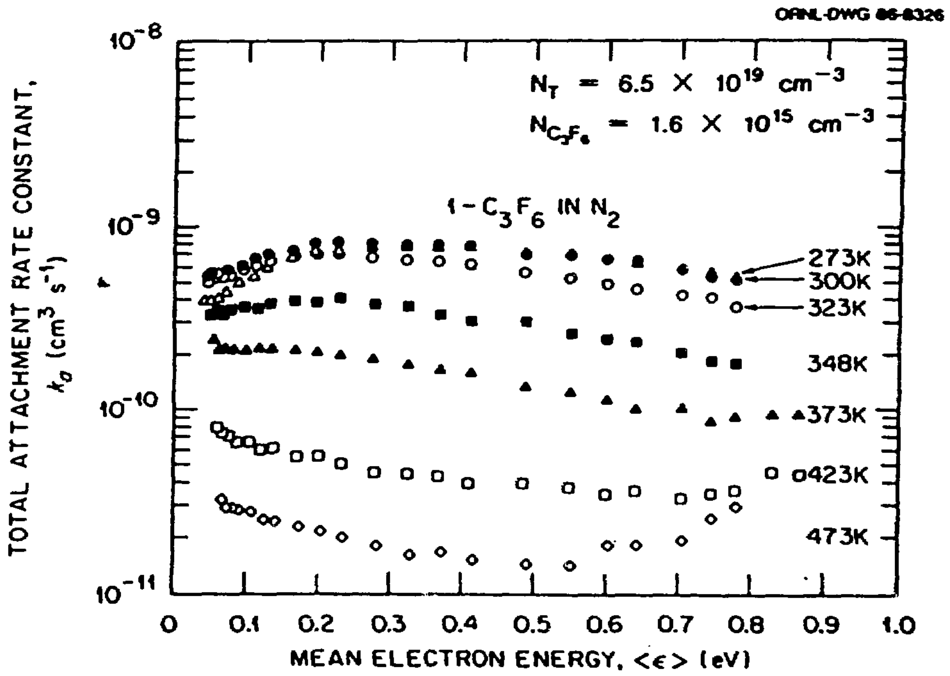

Fig. 4. k_a (<ε>, T) versus <ε> for 1-C$_3$F$_6$ (perfluoropropylene) (McCorkle *et al.*, 1983).

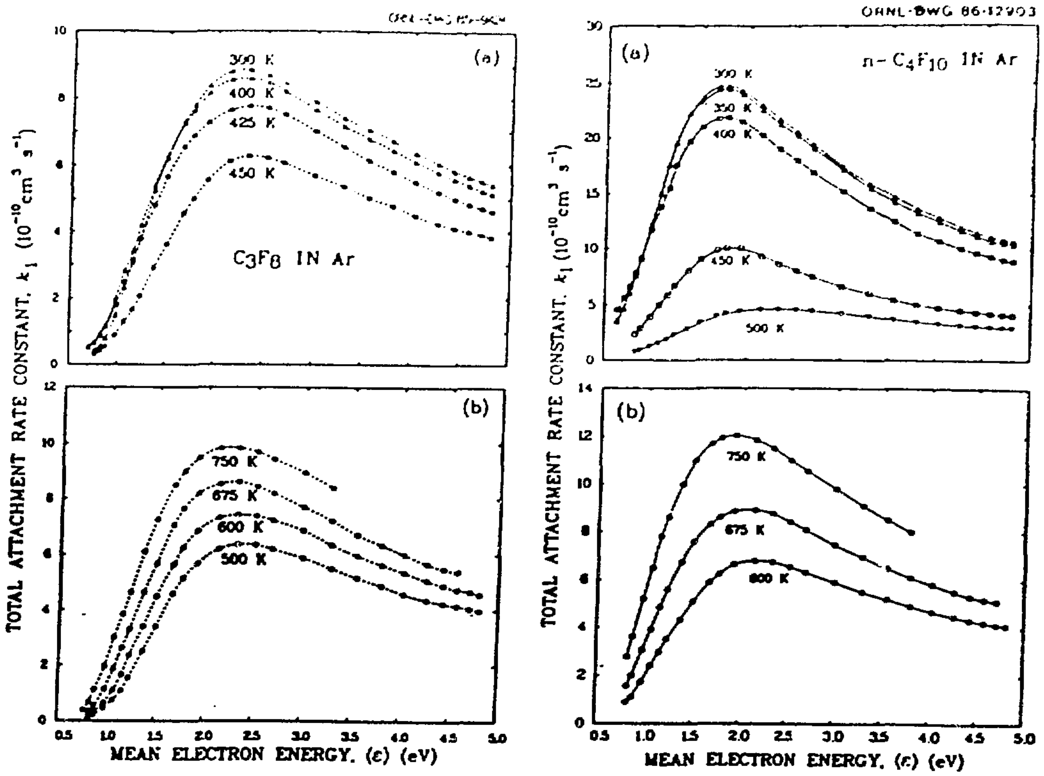

Fig. 5. k_a (⟨ε⟩, T) versus ⟨ε⟩ for (a) C_3F_8 (perfluoropropane) (Spyrou and Christophorou, 1985 b) and (b) n-C_4F_{10} (normal perfluorobutane) (Datskos and Christophorou, 1987).

b. *Those which optimize the operation of the switch in the closed, conducting stage.* Here the attachment rate constant, k_a (⟨ε⟩) [or cross section σ_a(ε)], must be small at low E/N and high T. In terms of electron attachment, a gaseous medium is needed which attaches strongly electrons when it is cold and weakly or not at all when it is hot. Such molecules (Figs. 2-5) — shown earlier (Christophorou and Hunter, 1984) to have high V_s by themselves or in mixtures, and thus to be good for the initial stage — may also be good for the closed stage because of their distinct property to attach electrons less efficiently at high T and — at least for some of them (e.g., C_3F_8) — also at low ε. The addition of these to a rare gas (e.g., He or Ar) or to a molecular buffer gas (e.g., H_2 or CH_4) increases the latter's conductivity at low E/N by increasing the electron drift velocity w (e.g., C_3F_8 in Ar, CH_4, or N_2) (Christophorou and Hunter, 1984; Hunter *et al.*, 1985). The conductivity of such mixtures, as we have shown earlier (Nakanishi *et al.*, 1985; Reinking *et al.*, 1986) can be further increased by the addition of minute quantities of a low-ionization onset additive.

c. *Further improvements in efficiency, repetition rate, and recovery.* These can be improved by reducing τ_f. It seems that the critical parameter to achieve this is that the gaseous medium has an effective ionization coefficient $\bar{\alpha}/N$ which increases rapidly with E/N close to $(E/N)_{\ell im}$. As can be seen from Fig. 6 for the case of C_3F_8 and especially n-C_4F_{10}, the $\bar{\alpha}/N$ versus E/N function would be even steeper (Hunter *et al.*, 1987).

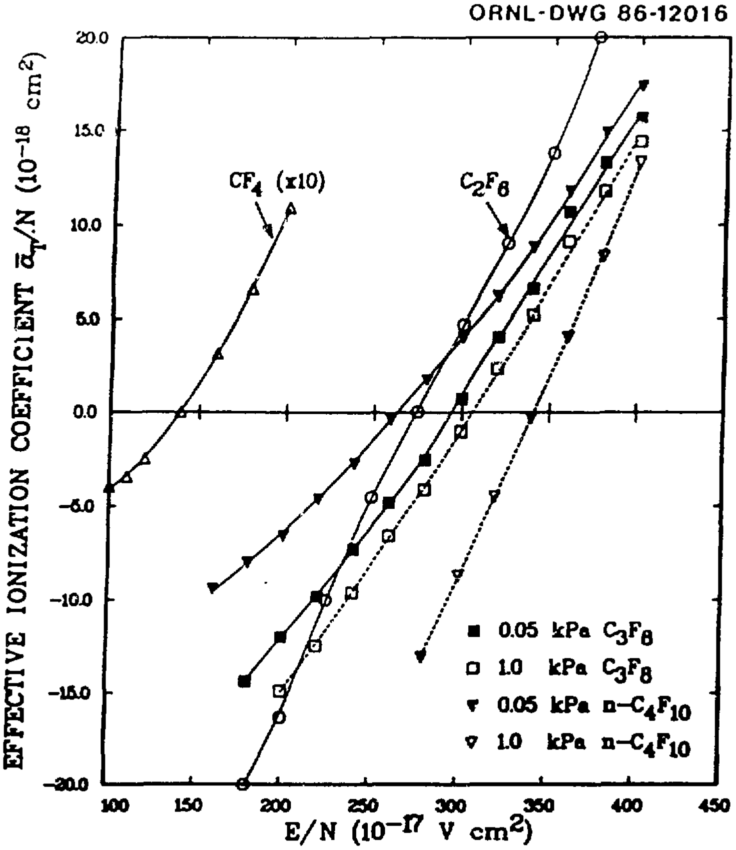

Fig. 6. $\bar{\alpha}_T/N$ versus E/N for CF_4, C_2F_6, C_3F_8, and n-C_4F_{10} (Hunter *et al.*, 1987)

CONCLUSION

On the basis of the above data and considerations, we identified the gaseous media in Table 2 as possible candidates for use in spark gap closing switches.

TABLE 2 Gases/Mixtures for Closing Switches

Binary Gas Mixtures

C_6F_6 or 1-C_3F_6 or n-C_4F_{10} or C_3F_8

or c-C_4F_8 or c-C_4F_6

with

He or Ar or H_2

Ternary Gas Mixtures

C_3F_8 or n-C_4F_{10} or c-C_4F_8

in

Ar or He + C_2H_2 or 2-C_4H_8

(or other low ionization onset
additive)

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