Journal of Al-Nahrain University Vol. 9(2), December, 2006, pp.81-89 Science

# Electron swarm phenomena in SF6+He and SF6+Ar mixtures

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## Abstract

A Boltzmann equation method has been used to study electron distribution function and electron swarm parameters in mixtures of gases (SF6+He and SF6+Ar). Distribution function, drift velocity, mobility, mean energy, diffusion, ionization and net ionization coefficients have been calculated as a function of percentage mixture ratio (k) ranging from zero (pure SF6) to 100% (for He or Ar) at a particular a reduced electric field E/p (where E is the electric field and p is the gas pressure). These parameters are also studied as a function of (k) at a particular $(E/p)_{cr}$, which breakdown occurs for the same mixtures gases. It is found in this work that, the swarm parameters in SF6+He and SF6+Ar mixtures are the same behaviors, which reflect the same properties of these inert gases. $(E/p)_{cr}$ for pure and mixture gases is determined from the graph for net ionization coefficient as a function of (E/p). It is also found, the mean electron energy is a constant at any values of (k) at $(E/p)_{cr}$ for two mixture gases (SF6+He and SF6+Ar). From this result, and because of the mean energy depends on distribution function only, therefore, one important conclusion is the distribution function for these mixture gases at $(E/p)_{cr}$ and for any value of (k) are identical. By inverse this conclusion, which mean that, it can be solved Boltzmann equation for a mixture gases at $(E/p)_{cr}$ for all range of (k) because the solution of Boltzmann equation (distribution function) are the same.

## Introduction

Sulphur hexafluoride, SF6, is one of the most important gases for use not only as electrical insulating but also as medium for gas lasers and plasma etching. Consequently, theoretical analysis of electron swarm parameters in SF6 or its mixtures is very important for predicting electrical properties of the gas as used in those applications [1].

Helium and Argon and mixtures of these two gases are often used as filling for electronic devices such as stabilizing valves, lasers, and spark chambers [2,3]. The use of mixture of SF6 and a cheep inert gases could eliminate some of the problem associated with pure SF6 and reduce the insulation cost [4,5].

Moruzzi and Craggs [6] carried out uniform field breakdown measurements in SF6+He and SF6+Ar mixtures. They noted that, as in pure SF6, all these mixtures tended to have a limiting value of $(E/p)_{cr}$. Similar to pure SF6 it is considered that the value $(E/p)_{cr}$ is reduced when the ionization coefficient are equal to attachment coefficient (net ionization coefficient is zero) for a particular mixture.

All the previous studies, which deal with the solution of Boltzmann equation to predict the distribution function and swarm parameters of mixture gases, the result are functions of (k) as a most important function at a particular E/p.

In the present work, the results are chosen accurately, which satisfy the breakdown criteria only. Therefore, the swarm parameters at breakdown criteria occur are considered as a function of (k) at a particular $(E/p)_{cr}$. In the present work, it is adopted that the breakdown criteria for pure gas occurs when a small increasing of (E/p) due to large increasing of ionization coefficient. The reason of this adopted due to the ionization is accumulative process. At this point, all results are deduced.

## Theory of calculation

The numerical methods used in this work are essentially the same as those in references [7, 8, 9]. The calculation is performed over a range of energy between zero and maximum energy, where the electron energy distribution function is sufficiently small. Therefore, the influence on the results of electron whose energies are above maximum energy may be neglected. The distribution function is calculated by using BOLSIG program [8] which solving numerically Boltzmann equation for SF6+He and SF6+Ar mixtures. The input data of cross-sections of SF6 are taken from Itoh[1], while the cross-sections of He and Ar are taken from[10, 11]. At the end stage, swarm parameters are calculated by injecting the result of distribution function in the equations below[7].

$$\frac{\alpha_m}{p} = \left(\frac{2}{m}\right)\left[k\,I_{m1} + (1-k)I_{m2}\right]/W_m \quad \text{..........(1)}$$

$$\frac{\eta_m}{p} = \left(\frac{2}{m}\right)\left[k\,II_{m1} + (1-k)II_{m2}\right]/W_m \quad \text{..........(2)}$$

$$W_m = \left(\frac{\varepsilon}{3}\right)\left(\frac{2}{m}\right)^{0.5}\left(\frac{E}{p}\right)S_{mm} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$D_m = \frac{1}{3}\left(\frac{2}{m}\right)^{0.5}\int_0^\infty \left(k\sigma_{M1}+(1-k)\sigma_{M2}\right)^{-1}\varepsilon\, d\varepsilon \ldots(4)$$

Where $\frac{\alpha_m}{p}$ is the ionization coefficient, $\frac{\eta_T}{p}$ is the attachment coefficient, $W_m$ is the electron drift velocity, $D_m$ is diffusion coefficient, e and m represent electron charge and electron mass respectively,

$$I_{mj} = \int_{\varepsilon_{Ij}}^{\infty} \varepsilon f_m(\varepsilon)\sigma_{Ij}(\varepsilon)d\varepsilon \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

$$H_{mj} = \int_0^\infty \varepsilon f_m(\varepsilon)\sigma_{Aj}(\varepsilon)d\varepsilon \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

$$S_{mm} = \int_0^\infty \left[k\sigma_{M1}(\varepsilon)+(1-k)\sigma_{M2}(\varepsilon)\right]^{-1}\times\frac{df_m(\varepsilon)}{d\varepsilon}\varepsilon d\varepsilon \ldots(7)$$

Where, j = 1, 2, $\sigma_{Ij}$, $\sigma_{Aj}$, $\sigma_{Mj}$ are ionization, attachment and momentum cross-sections respectively, $\varepsilon_{Ij}$ is ionization energy and $f_m$ is a distribution function for mixture gases.

These equations are solved by numerical by using MATLAP program. The present calculation is carried out varying E/p from 5V/(cm.torr) to 130V/(cm.torr) to make sure the $(E/p)_{crt}$ is in the ranges for these mixture gases.

## Result and Discussion

Hughes[12] shows that the electron energy distribution function for He at a definite E/p shifts very much toward high energy in comparison with that for SF6 which shows by Itoh[13] at the same value of E/p. it is shown from Fig.(1), the basic molecular properties of the individual gases similarly affect the distribution function in gas mixtures. Fig.(1 a,b and c) show that, the distribution function of He and Ar at different values of E/p are shifted very much toward not high energy as a result of Hughes[13], but toward low energy in comparison with that for SF6 (Fig. 1a). Fig. (1e, f) show that, the distribution function in SF6 is very large value than for He and Ar at low energies, which reflect very strong attachment and vibrational cross-sections, at the same E/p and lower value at high energies, which reflect very high excitation and ionization cross-sections.

Fig.(2 and 3) show that, the swarm parameters as a function of (k) in SF6+He and SF6+Ar mixtures respectively. The relationship between the net ionization coefficient and (k) for two mixture gases are linear at E/p=60V/(cm.torr) as shown in Fig.(2f) and (3f). From the point at which the net ionization coefficient is equal zero, it can be deduced the $(E/p)_{crt}$ value at any value of (k).

Fig.(2) and (3) also shown that, the mobility, drift velocity, diffusion coefficient and mean electron energy as a function of (k) at E/p=60V/(cm.torr) for SF6+He and SF6+Ar mixtures respectively. It is appear from these figures, the behaviour of these swarm parameters are the same. For example, for k < 0.4, these parameters decreases and for k > 0.4 they are increased for each mixture gases. Excluding from this results Fig.(3e) of SF6+Ar, the relationship is linear.

Fig.(4) and (5) show that, the swarm parameters as a function of (k) at E/p = $(E/p)_{crt}$ for the same mixture gases. Fig.(4a) and (5a) show that, the $(E/p)_{crt}$ as a function of (k) for two mixture gases. It appears from this figure the values of $(E/p)_{crt}$ decrease as increase of (k), in the other words, when increasing the percentage of He or Ar gases the breakdown happens early. Fig.(4b,c,d,e,f) and (5b,c,d, e, f) are found from the Fig.(4a) and (5a).

In Fig.(4f) and (5b), the mean electron energy as a function of (k) are constant at E/p = $(E/p)_{crt}$ for two mixture gases. From this result and because of the dependence of mean energy on distribution function only, very important conclusion, that the distribution function at $(E/p)_{crt}$ is a constant for any value of (k). This is very clear from the Fig.(6a, b), which is explain the behaviour of distribution function at $(E/p)_{crt}$ as a function of energy for 100%SF6 at $(E/p)_{crt}$=120 and 50%SF6+50%He at $(E/p)_{crt}$= 68V/(cm.torr) and 70%SF6+30%Ar at $(E/p)_{crt}$= 89 and 30%SF6 + 70%Ar at $(E/p)_{crt}$= 60V/(cm.torr) respectively. The distribution functions in Fig.(6a, b) are very consistent, but the consistent is slowly shifted when deals with pure gases at $(E/p)_{crt}$ as shown in Fig.(6c, d).

The behavior of mean electron energy differs from other parameters because the mean energy depends on the distribution function only but other parameters are depend on the data of cross-sections in addition of distribution function. This conclusion can help us to solve Boltzmann equation for a mixture of gases at $(E/p)_{crt}$ only.

## Conclusion

Electron swarm behavior in SF6−He and SF6−Ar mixtures are analyzed by using Boltzmann equation method which depends on the BOLSIG program. The result of Boltzmann equation analysis show that the providing set of cross-sections gives the values of swarm parameters such as ionization, net ionization and diffusion coefficient , mobility and mean energy for SF6+He and SF6+Ar mixtures. Also, all these parameters evaluated at $E/p = (E/p)_{cr}$. It is found that, the mean energy for these mixture gases as a function of k is constant at $(E/p)_{cr}$. One of very importent result that, the distribution function of these mixture gases are equal at $(E/p)_{cr}$. This result can enable us to solve Boltzmann equation for mixture gases at $(E/p)_{cr}$ only at any value of (k) if the values of $(E/p)_{cr}$ of mixture gases are presented.

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## المستخلص

استخدمت طريقة معادلة بولتزمان لدراسة دالة التوزيع للالكترونات ومعلمات حشد الالكترون لخليط الغازات (SF6+He ، SF6+Ar). دالة التوزيع، سرعة الانجراف، التحركية، معدل الطاقة، معامل الانتشار والتأين والتأين الكلي قد درست كدوال لنسبة الخلط k التي تتراوح من صفر (SF6 نقي) الى 100% (Ar او He نقيين) ولقيم معينة من E/p ، حيث ان E تمثل المجال الكهربائي و p يمثل الضغط. كذلك درست هذه المعلمات كدوال لنسبة الخلط للخليط الغازي وللقيم التي يتحقق فيها شرط الانهيار فقط ($E/p=(E/p)_{cr}$).

في هذا البحث وجدنا معلمات الحشد لكل من الخليطين (SF6−He) و (SF6+Ar) لهما نفس السلوك تقريبا والتعكس خواص الغازات المختلطة. وقد وجدنا ايضا ان قيم $(E/p)_{cr}$ بالنسبة لغاز Ar هي اعلى من قيم غاز He والتي تم ايجادها من الرسم بين صافي التأين كدالة لـ E/p لكلا الغازين. وجد ايضا من خلال البحث ان معدل الطاقة يكون ثابت لأي قيمة من k عند القيم $(E/p)_{cr}$ فقط. ولأن معدل الطاقة يعتمد على دالة التوزيع فقط، لذلك امكن الاستنتاج ان دالة التوزيع كدالة للطاقة تكون متطابقة لأي قيمة من قيم k على شرط ان تكون عند $(E/p)_{cr}$. من هذا الاستنتاج نستطيع ان نحل معادلة بولتزمان لخليط من الغازات وعند اي قيم من k على شرط معرفة قيم $(E/p)_{cr}$. لان دوال التوزيع تكون متطابقة.

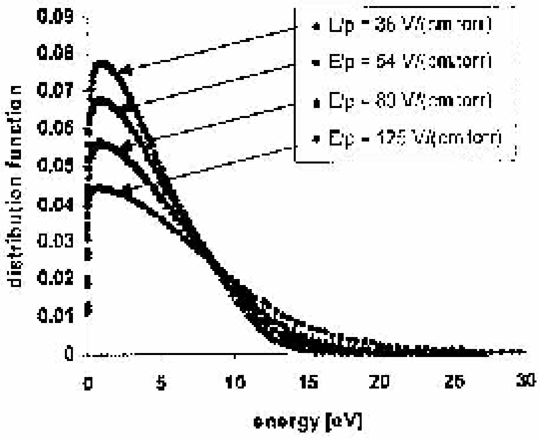

Fig.1a: Distribution function as a function of energy in SF6

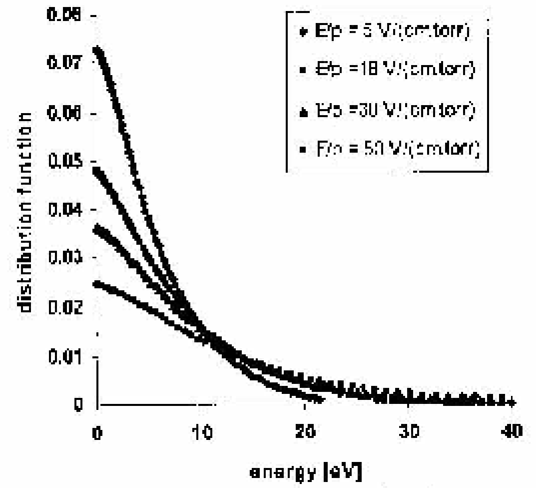

Fig.1b: Distribution function as a function of energy in He

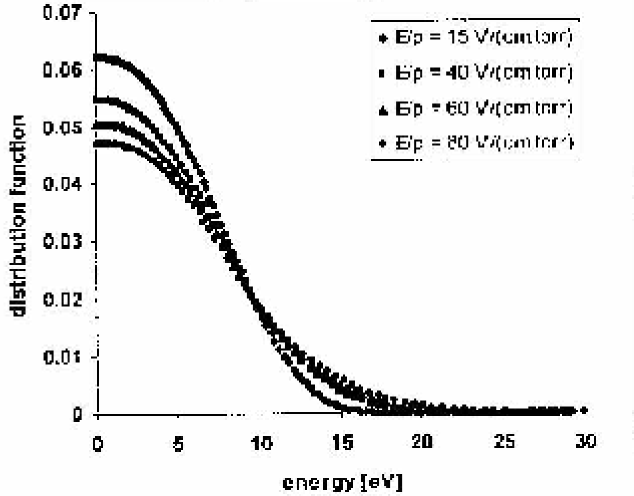

Fig.1c: Distribution function as a function of energy in Ar

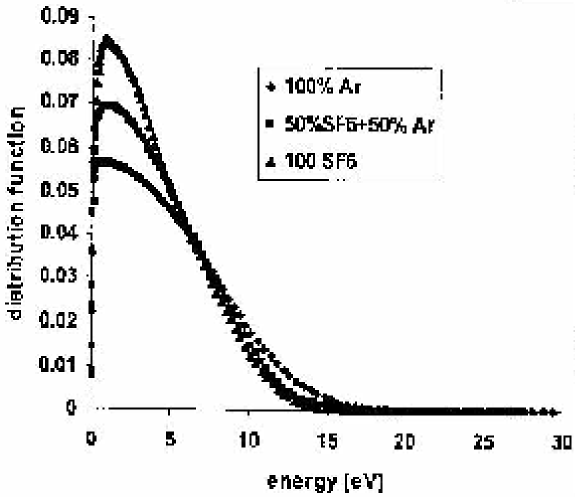

**Fig.1d:distribution function as a function of enrgy for SF6+Ar mixtures at E/p=30 V/(cm.torr)**

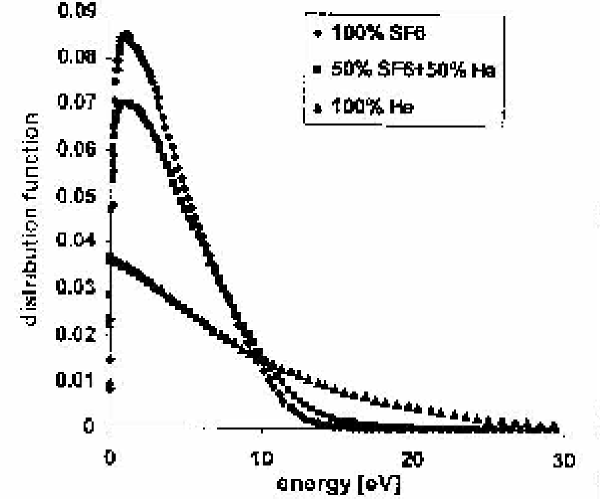

**Fig.1e:distribution function as a function of energy for SF6+He mixtures at E/p=30**

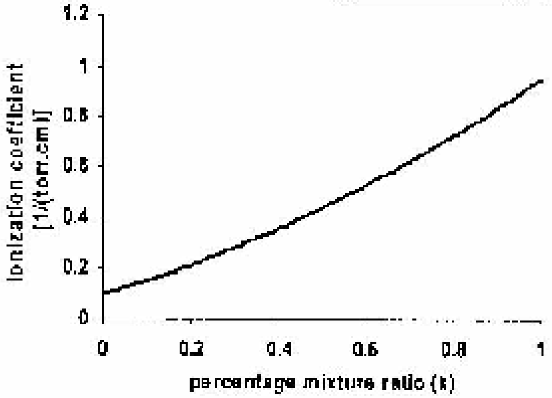

Fig. 2a: Ionization coefficient as a function of percentage mixture ratio (k) in SF6+He mixtures at E/p = 60 V/(cm.torr)

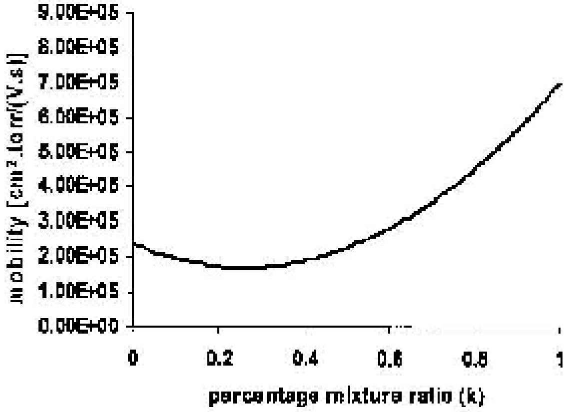

Fig. 2b: Mobility as a function of percentage mixture ratio (k) in SF6+He mixtures at E/p = 60 V/(cm.torr)

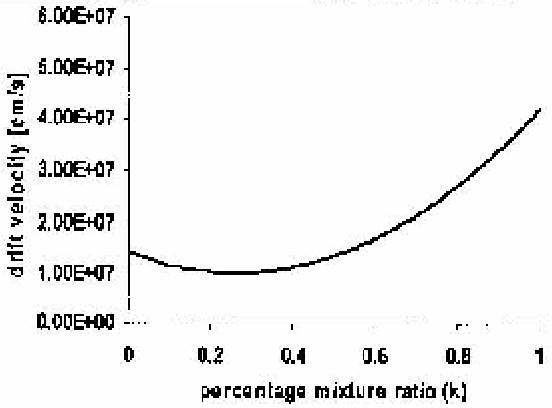

Fig. 2c:Drift velocity as a function of percentage mixture ratio (k) in SF6+He mixtures at E/p = 60 V/(cm.torr)

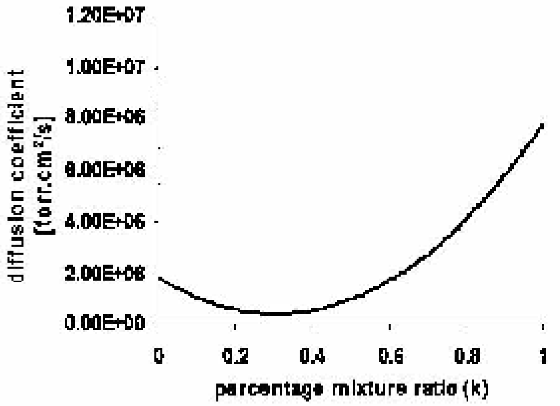

Fig. 2d:Diffusion coefficient as a function of percentage mixture ratio (k) in SF6+He mixtures at E/p = 60 V/(cm.torr)

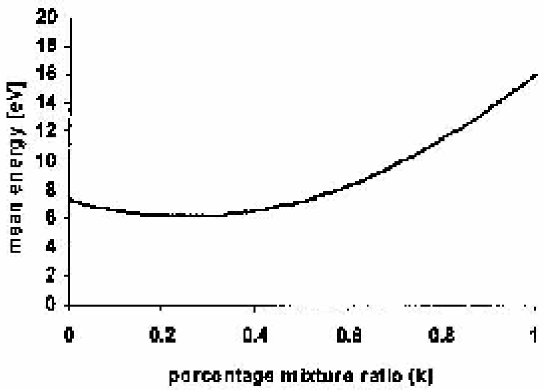

Fig. 2e: Mean energy as a function of percentage mixture ratio (k) in SF6+He mixtures at E/p = 60 V/(cm.torr)

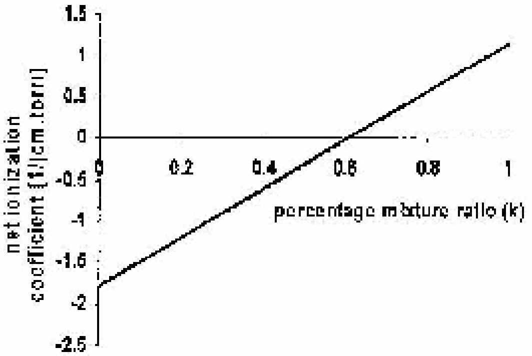

Fig. 2f: Net ionization coefficient as a function of percentage mixture ratio (k) in SF6+He mixtures at E/p = 60 V/(cm.torr)

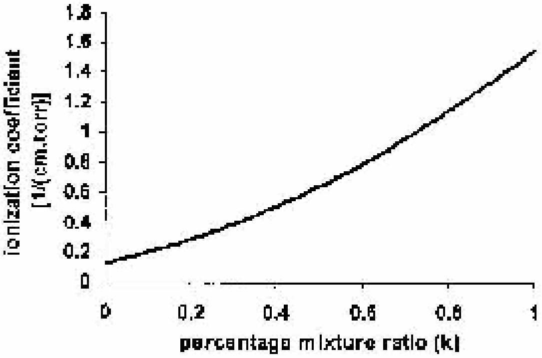

Fig. 3a: Ionization coefficient as a function of percentage mixture ratio (k) in SF6+Ar mixtures at E/p = 60 V/(cm.torr)

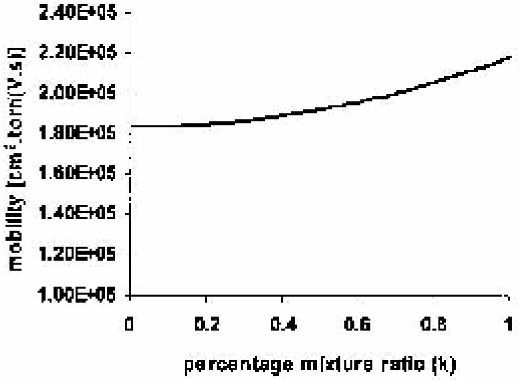

Fig. 3b: Mobility as a function of percentage mixture ratio (k) in SF6+Ar (mixtures at E/p = 60 V/(cm.torr

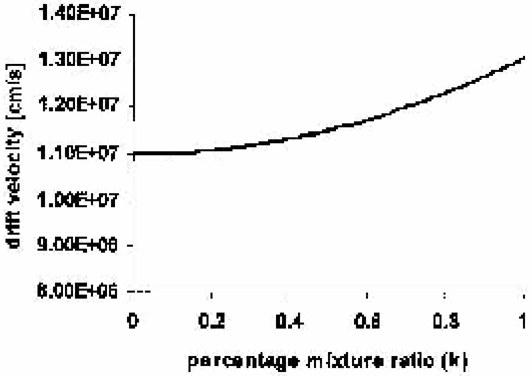

Fig. 3c: Drift velocity as a function of percentage mixture ratio (k) in SF6+Ar mixtures at E/p = 60 V/(cm.torr)

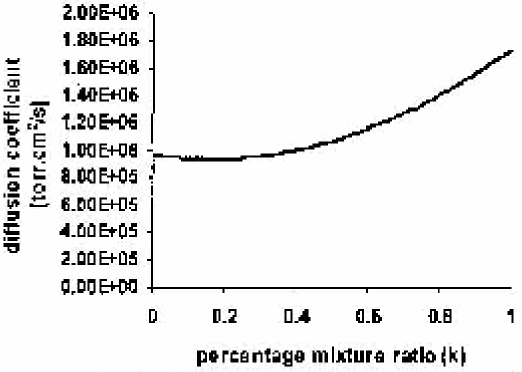

Fig. 3d: Diffusion coefficient as a function of percentage mixture ratio (k) in SF6+Ar mixtures at E/p = 60 V/(cm.torr)

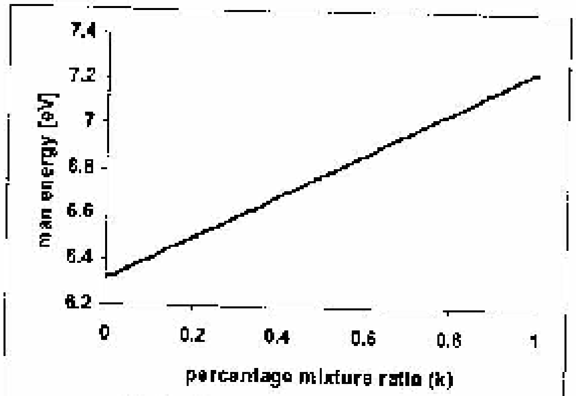

Fig. 3e: Mean energy as a function of percentage mixture ratio (k) in SF6+Ar mixtures at E/p = 60 V/(cm.torr)

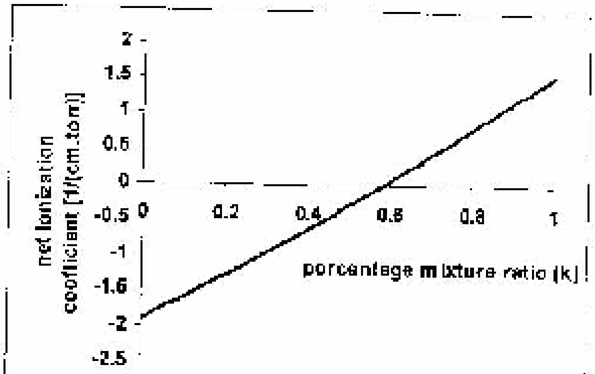

Fig. 3f: Net ionization coefficient as a function of percentage mixture ratio (k) in SF6+Ar mixtures at E/p = 60 V/(cm.torr)

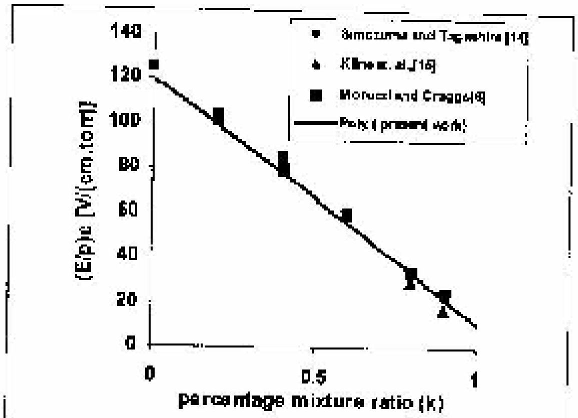

Fig. 4a: (E/p)c as a function of percentage mixture ratio (k) in SF6+He

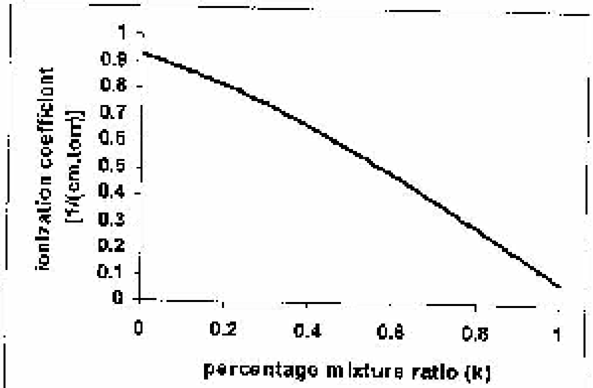

Fig. 4b: Ionization coefficient as a function of percentage mixture ratio (k) in SF6+He mixtures at (E/p)c

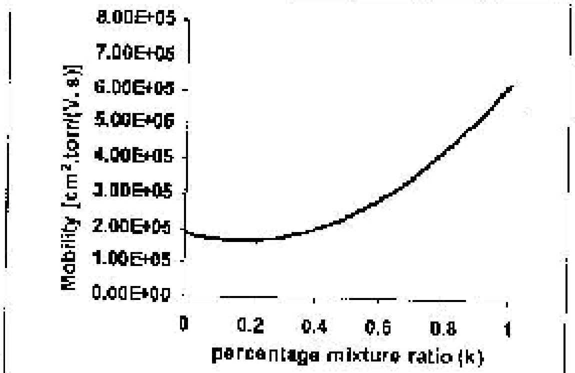

Fig. 4c: Mobility as a function of percentage mixture ratio (k) in SF6+He mixtures at (E/p)c

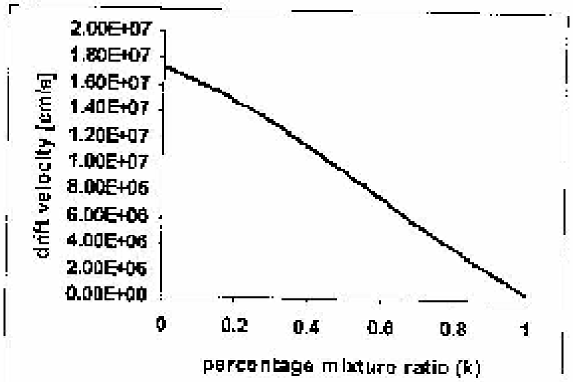

Fig.4d: Drift velocity as a function of percentage mixture ratio (k) in SF6+He mixtures at (E/p)c

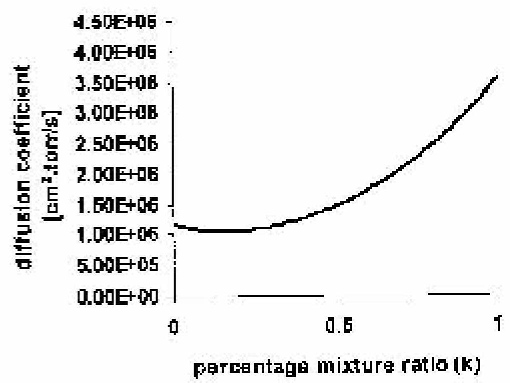

Fig. 4e: Diffusion coefficient as a function of percentage mixture ratio (k) in SF6+He mixtures at (E/p)c

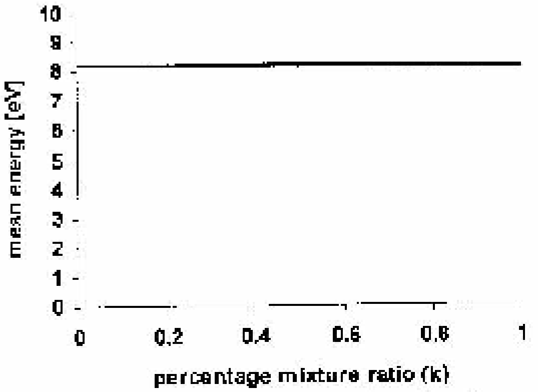

Fig. 4f: Mean energy as a function of percentage mixture ratio (k) in SF6+He mixtures at (E/p)c

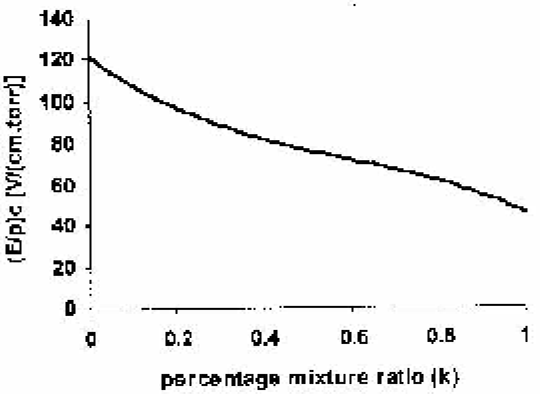

Fig. 5a: (E/p)c as a function of percentage mixture ratio (k) in SF6+Ar

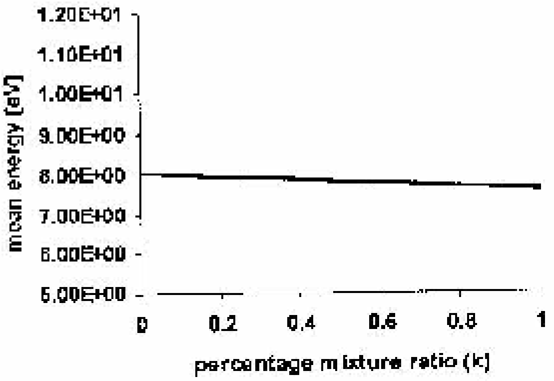

Fig. 5b: Mean energy as a function of percentage mixture ratio (k) in SF6+Ar mixtures at (E/p)c

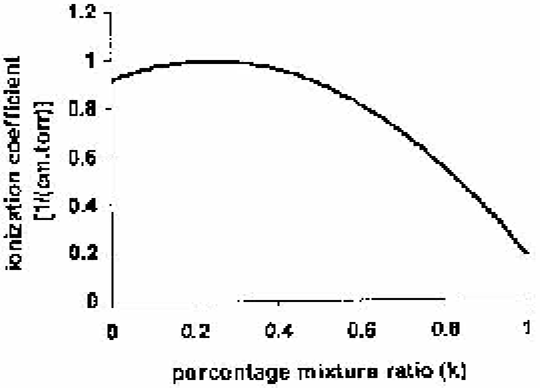

Fig. 5c: Ionization coefficient as a function of percentage mixture ratio (k) in SF6+Ar mixtures at (E/p)c

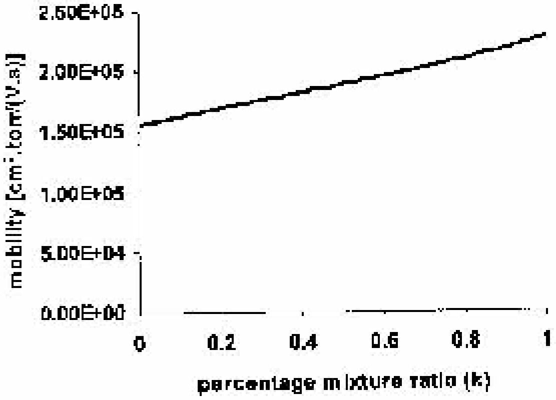

Fig. 5d: Mobility as a function of percentage mixture ratio (k) in SF6+Ar mixtures at (E/p)c

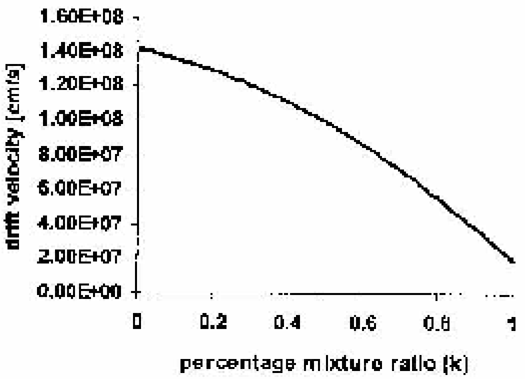

Fig. 6e:Drift velocity as a function of percentage mixture ratio (k) in SF6+Ar mixtures at (E/p)c

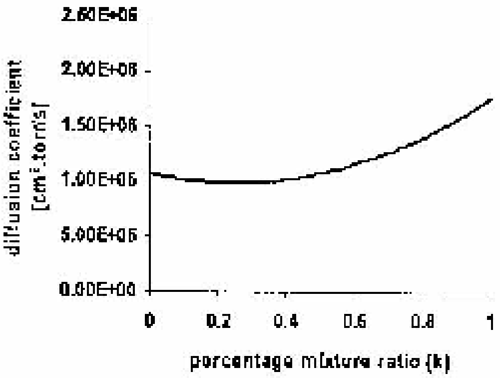

Fig. 5f: Diffusion coefficientas a function of percentage mixture ratio (k) in SF6+Ar mixtures at (E/p)c

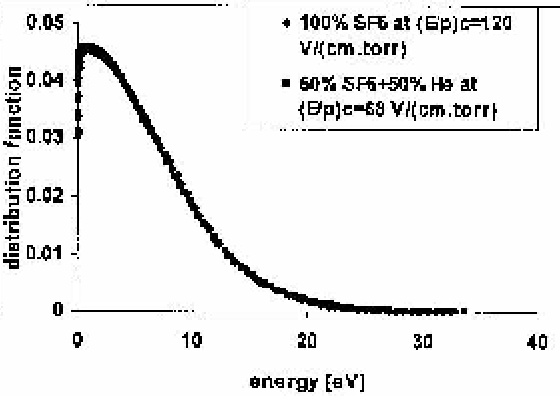

Fig.6a:Distribution function as a function of energy for 100% SF6 at (E/p)c=120 V/(cm.torr) and 50% SF6+50% He at (E/p)c=58 V/(cm.torr)

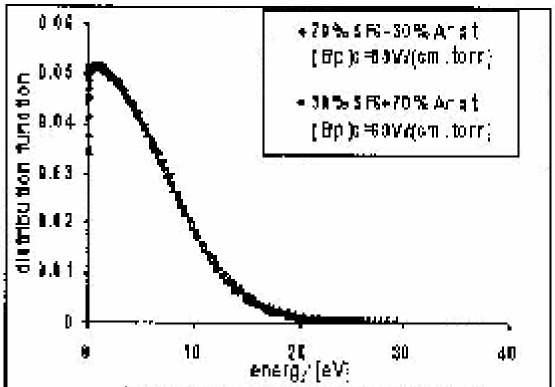

Fig.6b: Distribution function as a function of energy for 70% SF6+30%Ar at (E/p)c=69 V/(cm.torr) and 30% SF6+70% Ar at (E/p)c=60 V/(cm.torr)

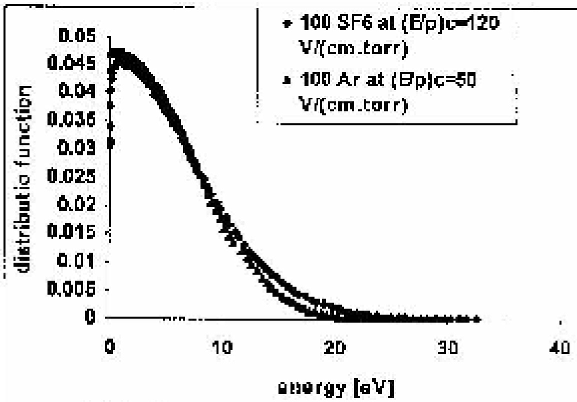

Fig.6c: Distribution function as a function of energy for 100% SF6 at (E/p)c=120 V/(cm.torr) and 100% Ar at (E/p)c=50 V/(cm.torr)

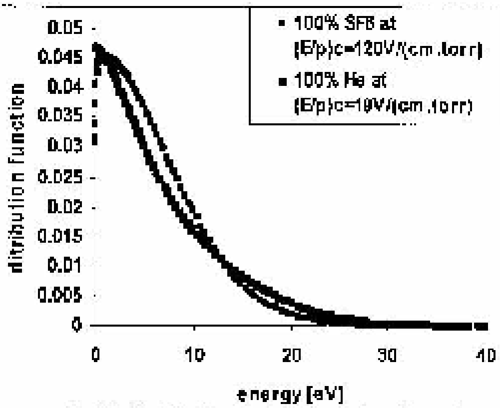

Fig.6d: Distribution function as a function of energy for 100% SF6 at (E/p)c=120 V/(cm.torr) and 100% He at (E/p)c=19 V/(cm.torr)