The development of a magnetic ion-source with high ionisation efficiency

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Introductory.

Though the magnetic ion-source offers several advantages compared with other types of sources, it is seldom used since the early work of A. Th. FINKELSTEIN[1]) and M. v. ARDENNE[2,3]). An exception is found by W. MAAS[4]).

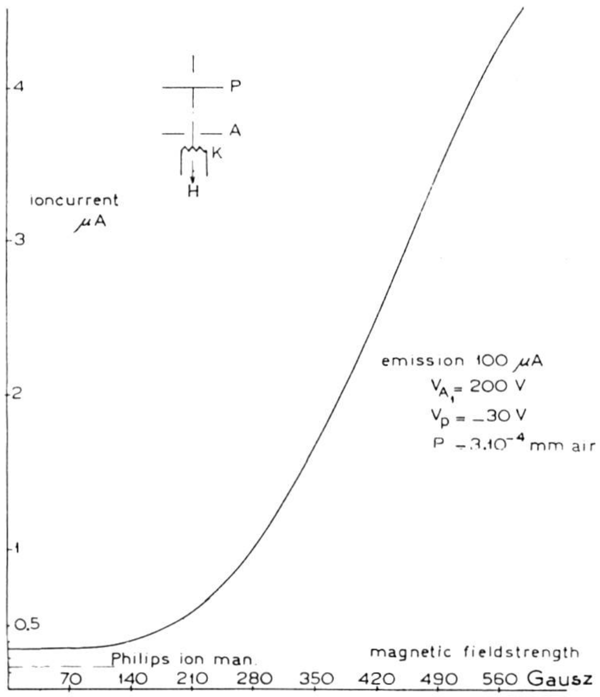

Fig. 1.

The principal advantages turn out to be:

1. the powerconsumption is low — power is obtained from storage-batteries. Consequently the source and its complete power supply can be put at a high potential;
2. gaspressure and hence gasconsumption are low;
3. high currents of monokinetic ions are obtained, with up to 50% atomic ions in the beam;
4. no artificial cooling is required.

Preliminary experiments.

In a magnetic ion-source the probability for an electron to ionize the gas is increased by a magnetic field which forces the electrons to describe a spiral. For this reason the first thing one is interested in is the relation between magnetic fieldstrength and ion current. This means to get some insight into the amount in which the spiralizing movement of the electrons increases the length of their orbits.

The result is to be found in fig. 1, showing that an increase in ion current up to a factor 15 easily can be produced.

Space-charge effects.

With higher cathode emission space-charge effects will occur. When repeating the former measurement a result as shown in Fig. 2 is obtained. In this graph both ion-current and emission have been

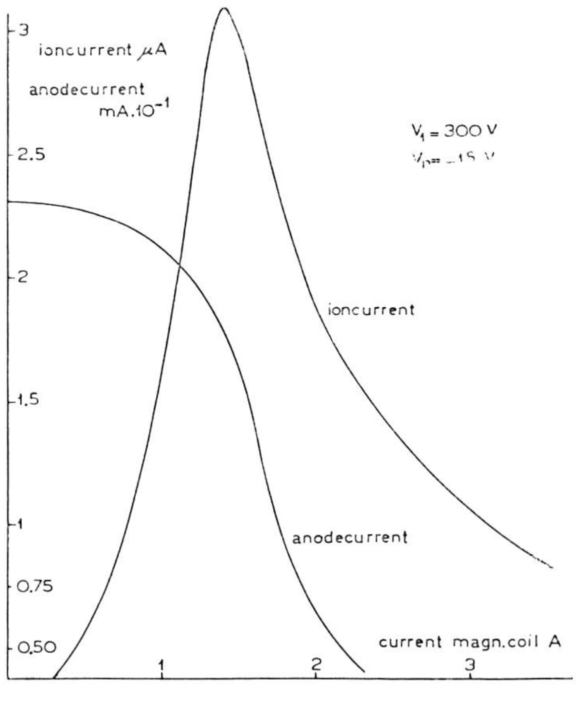

Fig. 2.

plotted against the magnetic field strength. The decrease of anode current is caused by a strong negative space charge introduced by the action of the magnetic field. Obviously the magnetic field narrows the electrons into a beam, representing a zone of high negative space charge. Owing to loss of speed the majority of the electrons in the beam loses for a certain pair of values of anode tension and the magnetic field strength the power to ionize the gas, so that the ion-current decreases.

We assume the electron space-charge density to be proportional to the magnetic field H and reciprocally proportional to the electron speed $\{V_A\}^{1/2}$, where V_A is the anode tension.

Assuming secondly the maximum ion-current in each case to occur as soon as a critical negative space-charge is reached, a straight line is to be expected if in each maximum of ion-current H is plotted against the corresponding value of $\{V\}^{1/2}$. Fig. 3 shows the results of a series of measurements.

In conclusion: the ion-current output of a magnetic source will be limited by negative space-charge introduced by the magnetic field. Compensation of the negative space-charge can readily be obtained by increasing the anode tension. It turns out to be

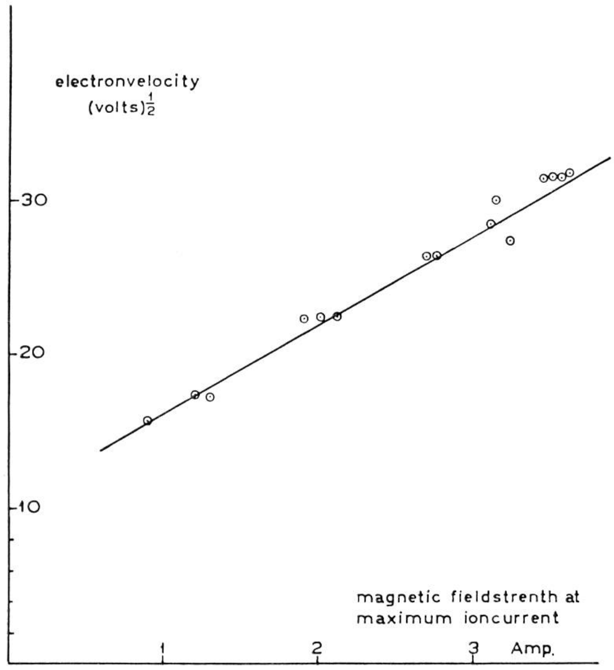

Fig. 3.

possible to build an ion-source operating at pressures down to $5 \cdot 10^{-5}$ mm. Hydrogen and giving an ion current up to 0·3 mA at a plate tension of 2 to 3 kV. It is however desirable to build a low-tension source and by this demand the source has to be operated at higher pressure.

Looking at Fig. 4, where once more the ion-current and the anode current are plotted against the magnetic field, this time for several pressures, it is clear that increase of pressure renders an automatic compensation of negative space-charge. At higher pressures the shape of the curves is changed: the ion current decreases less rapidly and finally there is a tendency to increase. Moreover the maxima can be seen to shift to higher magnetic field strength when the pressure increases. Increasing pressure means growing ionisation density which implies introduction of positive space-charge. The result is that a stronger magnetic field can be used before the critical negative space-charge is reached. Bearing in mind that the ion-velocity is small compared with the electron-velocity, complete

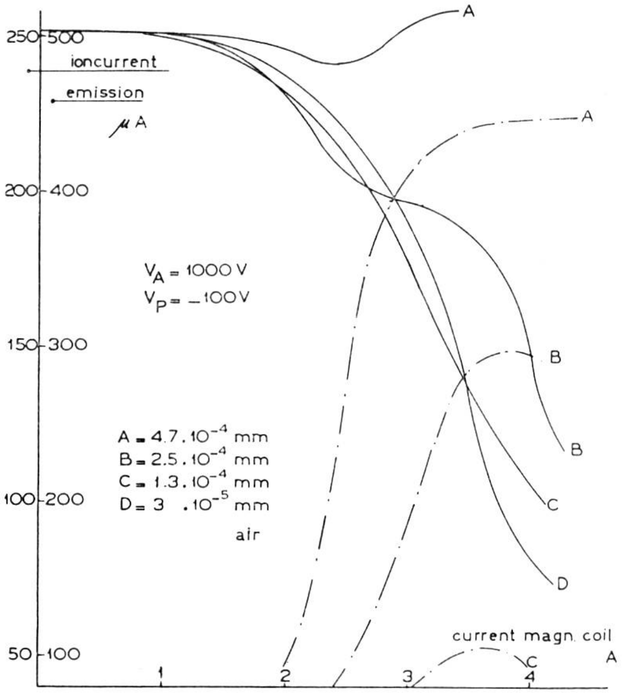

Fig. 4.

space-charge equilibrium may be obtained when the pressure is sufficiently increased and in this case strong ion-currents may be expected.

The oscillation of electrons.

The formation of space-charge equilibrium is greatly stimulated by the oscillation of secundary electrons, i. e. electrons generated by ionisation of the gas. It may be remarked that the primary electrons, i. e. electrons emitted by the cathode, will return into the cathode after performing one oscillation. The secondary electrons are formed at random in the ionisation space, hence they have a good upportunity to oscillate, so that they are far more effective for ionisation than the primary electrons. In a magnetic source the primary electrons only serve to start operation. As soon as a critical gas pressure has been reached the secondary electrons become far more essential as they have a much higher chance to oscillate. It is therefore necessary to stimulate the existence of electrons of adequate average speed while, with an eye to space-charge balance, the ion-velocity must be kept as low as possible. Ion extraction therefore must be perfomed by diffusion.

When the critical ionisationdensity mentioned before is passed the ion-current increases to values up to 5 mA. The same is observed when, operating at the critical pressure the magnetic field is increased. The source operates quite stable in a higly efficient state which we have called "superstate". The most important property of this state is its irreversability, i. e. when operating in superstate obtained by increasing the magnetic field, it is possible to decrease the field without considerable loss of ions — untill the field reaches a definite value and the ion current drops to about 10% of its former value. This value corresponds to the normal ion-output of the source operating out of superstate.

The same can be observed by varying the pressure.

The larger the primary emission has been chosen the sooner the superstate will be observed and the larger the ion-output of the source will be. Recently we build a magnetic source equipped with water cooling. At a pressure of 0.5 micron of hydrogen ion currents up to 20 mA are obtained.

The percentage of atomic ions.

Magnetic analysis of the beam shows for hydrogen a proton percentage of about 50%, a figure which is surprising high for a source containing metallic surfaces. It however must be remarked that the tantalum anode system of the source runs red-hot during operation. Atomic recombination being a three-body phenomenon, recombination mainly occurs on surfaces covered with adsorbed atoms. A high temperature will prevent atoms sticking to these surfaces: the thermal equilibrium $H_2 \rightleftharpoons 2H$ is shifted to the right at high temperature, this being a reason for the satisfying proton-output of the source.

Technical development, drawing Fig. 5.

The ion source system housed in the lower end of the central copper tube A, consists of a tungsten cathode and a set of three anodes. The lower two represent a field-free space, the first anode has a slightly different potential for focussing purposes. The ion exit-canal and so the entire envelope of the source are kept at cathode potential. The anode system is insulated from the copper tube by means of a pyrex cylinder which also provides central adjustment.

The drawing shows that the dimensions of the ionisation space are very small and the space charge compensation makes it easy to get the ions out of the source. Measurement shows this to amount up to 50%.

The housing of the source consists of the copper tube *A*, welded to the iron plate *B*, centrally bearing the ion exit canal.

Concentrically with *A* is the iron tube *C*, closing via the iron upperplate *D* and the solid iron rod *E* the magnetic circuit of a

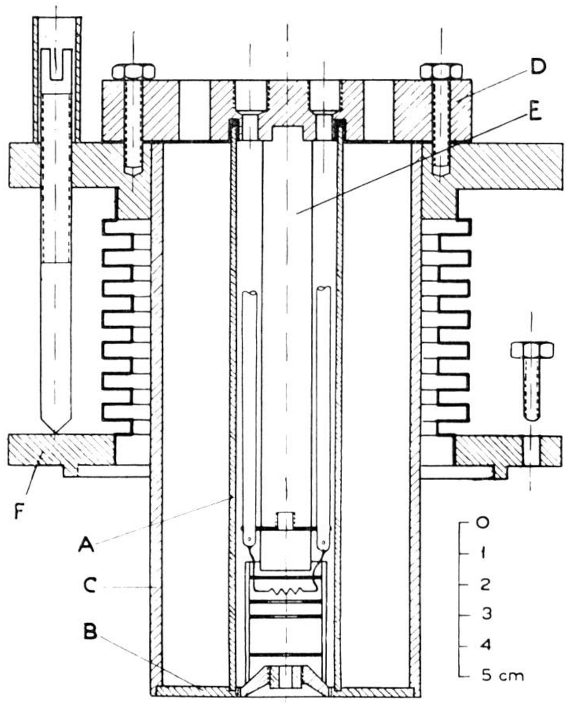

Fig. 5.

coil housed in the space between *A* and *C*. The entire magnetic field is between the iron rod *E* and the ion exit-canal.

The plate *D* is provided with a groove fitting the copper tube. A rubber ring assures vacuum thightness. Adjustment of the source is obtained by means of vacuum bellows and three screws.

Results.

When at high vacuum the cathode of the source is adjusted to give a primary emission of about 10 mA at a plate tension of 150 *V*, the current increases to 50 mA at a gas pressure of 0.6 micron hydrogen and the source is in "super state". The ion output passing an exit canal of 3 mm diam. will amount to 1 mA. Summarizing we find:

gas pressure	0.6 micron hydrogen
normal emission	10 mA
total emission	50 mA
anode tension	100—300 V
magnetic field	1000 Gauss

On increasing the input power the ion current rapidly increases,

emission	300 mA
ion current	3 mA

When the pressure is increased up to 0.8 micron, the ion current will increase to 5 mA.

Cold emission sources.

The principal drawback of the magnetic source is the presence of a hot cathode having a limited lifetime.

When the acceleration equipment posesses sufficient pumping speed, the cathode may be omitted and after slight alterations the source will operate with cold emission as described by PENNING[5]) and recently by R. KELLER[5]), showing superstate like the hot cathode type. The presence of a field-free space in the anodesystem as described before is strictly required to get stable operation.

Operating data are:

gaspressure	10 micron H_2
plate current	20 mA
plate tension	800 V
magnetic field	1000 Gauss
ion current	2 mA
diam. ion exit canal	3 mm

The proton percentage has not been measured so far, but after 10 minutes operation the discharge in the source becomes bright red, so that we may expect the proton output is high.

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