

## THE DEVELOPMENT OF A MAGNETIC ION-SOURCE WITH HIGH IONISATION EFFICIENCY

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### Summary

Starting from the principle given by A. T h. F i n k e l s t e i n<sup>1)</sup>, M. v o n A r d e n n e<sup>2) 3)</sup> and W. M a a s<sup>4)</sup>, further development of the magnetic ion-source has been undertaken. The instrument has been designed especially for use with a 800 kV neutron generator described by W. M a a s<sup>4)</sup> and under normal operating conditions the source will have an output of 1 mA ion current. After increasing input power several milliamperes may be obtained.

The principal advantages of the magnetic source turn out to be:

1. the power consumption is low, power is obtained from storage batteries. Consequently the source and its complete power supply can be put at a high potential with respect to the earth;
2. no artificial cooling is required;
3. gas-pressure and hence gas-consumption are low;
4. a homogeneous ion beam — with respect to ion velocity — is obtained.

*Preliminary experiments.* In a magnetic ion source the probability for an electron to ionize a gas molecule is increased by a magnetic field which forces the electron to describe a spiral. For this reason the first thing to claim one's interest is the relation between magnetic field-strength and ion-current as this would give some idea of the

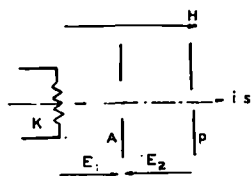


Fig. 1. Experimental magnetic source.

increase of the ionisation probability with the spiral movement of the electrons. The measurement was performed with a simple type of ionsource according to fig. 1. It consists a of tungsten cathode *K*, a perforated anode *A* and the third electrode *P*. *P* is about at cathode potential and *A* is positive with respect to the cathode. The instrument is put between the poles of an electromagnet and is operated

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at low emission and high anode tension in order to avoid space-charge effects.

The result is to be found in fig. 2, showing that an increase in ion current, flowing to the electrode  $P$  up to a factor 15 can easily be produced.

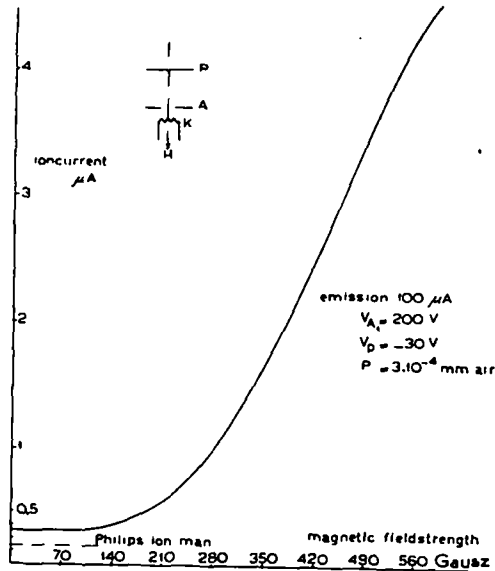


Fig. 2. Relation between ion-current and magnetic field not affected by space-charge.

*Space-charge effects.* With higher emission, space-charge effects will occur. With a view to introducing these effects in a simple case, the flat perforated anode  $A$  was replaced by a nickel ring of about 0.5 inch diameter. Repeating the first measurement a result as shown in fig. 3 is obtained. In this graph both the ion current and the emission have been plotted against the magnetic field strength. The decrease of the anode current is caused by a strong negative space charge introduced by the action of the magnetic field.

When both  $A$  and  $P$  are made positive it turns out that the electron current to  $A$  decreases rapidly to zero when the magnetic field increases. Meanwhile the current to  $P$  increases and the sum of both currents is constant and equal to the cathode emission. Obviously the magnetic field narrows the electrons into a beam, representing a zone of high negative space charge. Owing to loss of speed the major

rity of the electrons in the beam loses for a certain pair of values of the anode tension and the magnetic field strength, the power to ionize the gas, so that the ion-current decreases.

In fig. 4 a graph is shown, analogous to fig. 3 but measured at different gas-pressures and anode tensions. It may be observed that in this region of low pressure the location of the ion current maximum depends on the anode tension only and not on the pressure. As increase of plate tension means decrease of negative space charge, a shift to higher magnetic field is allowed before that maximum is reached and hence — according to fig. 2 — a considerable gain of ion

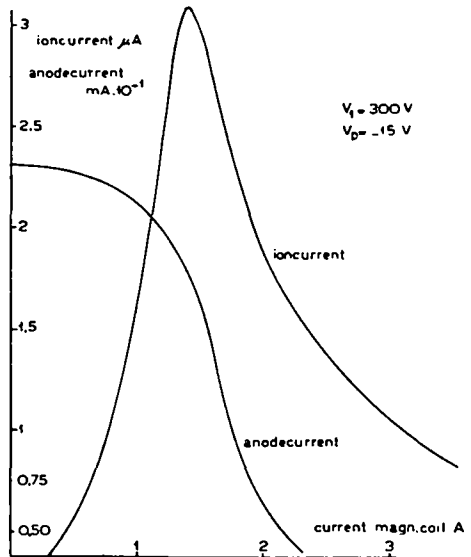


Fig. 3. Both ion-current and anode-current as a function of the magnetic field showing influence of space-charge.

current may be expected. We assume the electron space-charge density to be proportional to the magnetic field  $H$  and reciprocally proportional to the electron speed  $(V_A)^{\frac{1}{2}}$ . Assuming moreover the maximum ion current in each case to occur as soon as a critical negative space charge density is reached, a straight line is to be expected, if in each maximum  $H$  is plotted against the corresponding value of  $(V_A)^{\frac{1}{2}}$ . Fig. 5 shows the results of a series of measurements.

Finally: the ion current output of a magnetic ion source will be limited by the negative space charge density introduced by the magnetic field.

*Compensation of negative space charge.* As already mentioned one can get rid of the complication due to space-charge by increasing the anode tension. It turns out to be possible to build an ion source operating at very low pressure — down to  $5 \cdot 10^{-5}$  mm Hg Hydrogen — and giving an ion current up to 0.3 mA at a plate tension of 2 to 3 kV. As a matter of fact a source of this type successfully produces ions of deuterium in a 100 kV neutron generator operating in this laboratory <sup>5</sup>). It is, however, desirable in our case to build a low-tension source and this requires the source to be operated at higher

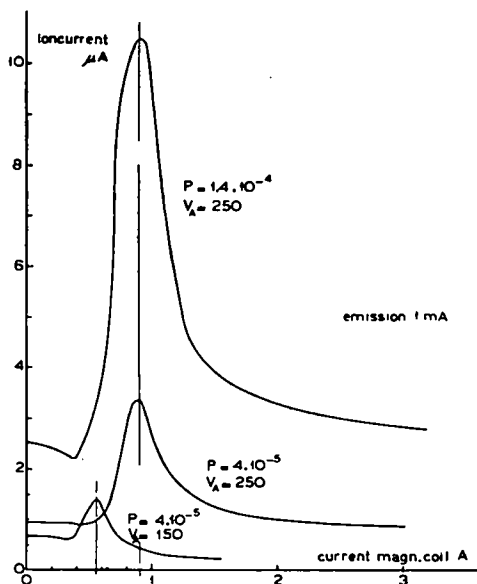


Fig. 4. Ion-currents as a function of the magnetic field showing that the position of the maximum in the low pressure region depends only on the anode-tension.

pressure. Looking at fig. 6, where the ion-current and the anode current are once more plotted against the magnetic field, this time for a higher anode tension and several pressures, it is clear that an increase of pressure causes an automatic compensation of negative space charge. At low pressure nothing new is to be observed but at higher pressure the shape of the curves is changed: the ion current decreases less rapidly with the magnetic field and finally there is a tendency to increase. The emission curves show the same behaviour. Moreover, the maxima can be seen to shift to higher magnetic field

strength when the pressure increases. Obviously 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. Complete

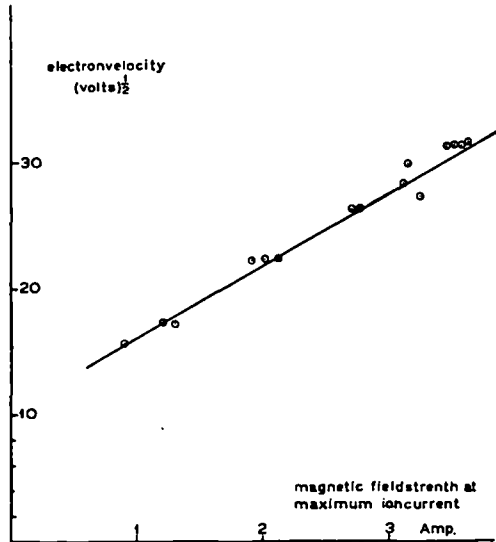


Fig. 5. The linear relation between electron velocity and the magnetic field at the maximum of ion-current.

space charge equilibrium may be obtained when the pressure is sufficiently increased. According to the results gained hitherto strong ion currents may be expected.

*The oscillation of electrons.* The formation of space charge equilibrium is greatly stimulated by the oscillation of secondary electrons, i.e. electrons generated by ionisation of the gas. It may be remarked that the oscillation probability for primary electrons that did not collide is small. Most likely they return into the cathode after performing one oscillation. Consequently when the ion current is measured in a low pressure region the current is a linear function of the pressure. When, however, the region has been reached where the ionisation density grows to a considerable amount, secondary electrons become effective for the ionisation and the ion current grows faster than before. As these electrons are formed at random in the ionisation space, they have a good opportunity to oscillate, so that they are far more effective for ionisation than the primary electrons. By this

operation and bearing in mind that the ion-velocity is very small compared with the electron velocity, space charge compensation will be reached at low pressures if the source is constructed in the right way (see next chapter).

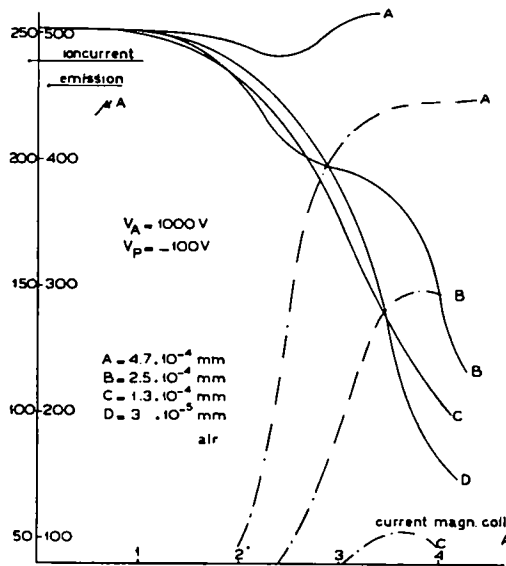


Fig. 6. Both ion-current and emission as functions of the magnetic field showing the gradual compensation of negative space-charge when the pressure is increasing.

Summarizing: we may state that in a magnetic ion source the primary electrons only serve to start the operation. As soon as a critical gas-pressure is reached the secondary electrons become far more essential as they have a much greater chance to oscillate. It is, therefore, necessary to stimulate the existence of oscillating electrons of adequate average speed while the ion-velocity must be kept as low as possible. Ion extraction from the ionisation space must therefore be performed by diffusion.

By this explanation the magnetic ion source seems to be closely related to the high frequency source. The former, however, has the advantage of being self-oscillating.

It is interesting that one can show quite simply the magnetic source generates *H.F.* currents. When inserting a neon lamp between cathode and anode and using small condensers to prevent flowing

d.c. through the lamp, ignition of the latter can be observed. The relation between ion output and H.F. amplitude will be studied in due course. Finally, we remark that as soon the critical gas-pressure mentioned before is passed the ion current increases to values as high as 5 mA. The same is observed when, operating at the critical pressure, the magnetic field is increased. The source operates quite stably in a highly efficient state which we have called "superstate". The most important property of this state is the irreversibility, i.e. when operating a source in superstate obtained by increasing the magnetic field, it is possible to decrease the field without considerable loss of ions — until the field reaches a definite value and the ion current suddenly drops to about 10% of its former value. This value corresponds to the normal ion output of a source operating in a non-superstate. The same can be observed by varying the pressure, though the effect is not so clear. Increasing pressure suddenly brings about the superstate. Ion output in superstate is still a function of pressure. When, however, the pressure becomes too high the ion output decreases owing to collisions.

Operating in superstate the pressure may be decreased and the ion output decreases slowly. When, again, a critical value is passed the ion current drops to a small value corresponding to the normal state. The larger the primary emission has been chosen the sooner the superstate will be observed and the lower the operating pressure in the source will be.

*Technical development* <sup>6)</sup>. Apparently a well-operating magnetic ion source should possess an ionisation space in which the space charge equilibrium may easily be formed. The better the construction the lower the pressure at which that source will operate. It soon appears that the single-anode system does not operate satisfactorily. The ion density becomes important at pressures which are too high for our purpose as the ions are quickly removed from the ionisation space by the electric field between the anode and ion exit canal ( $A$  and  $P$  in fig. 1). Moreover, the ion energy is not constant but fluctuates over a range between zero and  $V_A$  electron-volts, depending on the place where they are formed. An improvement is obtained when the anode  $A$  is replaced by a cylinder, thus creating some kind of field-free space. The equilibrium will be formed more easily as the ion velocity is principally determined by diffusion.

A simpler solution is the use of a system of electrically connected

flat anodes. This way has been adopted in the source which is in actual use — see fig. 7. 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 the field-free space, the first anode has a slightly different potential for focussing purposes. The ion exit-canal and thereby 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.

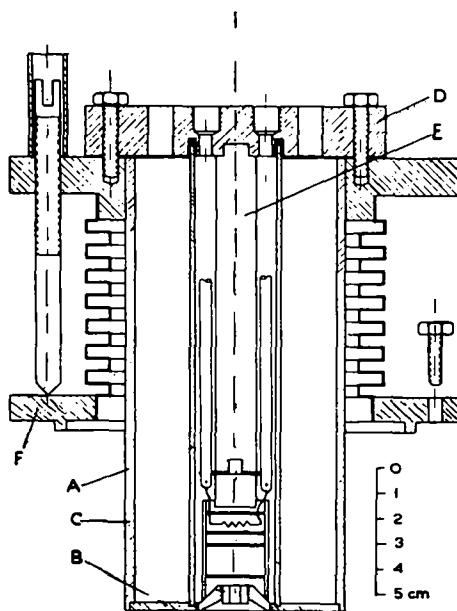


Fig. 7. Technical construction of a magnetic ion source.

The diagram 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 carrying the ion exit canal. Concentrically with *A* is the iron tube *C*, closing via the iron topplate *D* and the solid iron rod *E* the magnetic circuit of a coil housed in the space between *A* and *C*. The entire magnetic field lies between the iron

\*) 7 windings of W-wire, 0.2 mm diam., diam. of each winding 2.5 mm.



rod *E* and the ion exit canal. The plate *D* is provided with a groove fitting the copper tube. A rubber ring ensures vacuum tightness. 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 saturation current 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 "superstate". The ion output passing an exit canal of 3 mm diam. will amount to 1 mA, as measured in a Faraday-cage at a tension of 20 kV at distance of 5—10 mm. from the ion exit canal.

Summarizing we find:

gas-pressure . . . . .	0.6 micron Hydrogen
normal emission . . . . .	10 mA
total emission . . . . .	50 mA
anode tension . . . . .	100—400 V
magnetic field . . . . .	1000 Gauss
ion current . . . . .	1 mA, 50% protons

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 increases to 5 mA.

*Remark:* the ion extracting field is not shaped according to Pierce. So far we have not found any indication of space-charge limitation of the ion current.

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