HEAVY ION ACCELERATORS OF THE FUTURE
Ch. Schmelzer

To cite this version:
Ch. Schmelzer. HEAVY ION ACCELERATORS OF THE FUTURE. Journal de Physique Colloques, 1972, 33 (C5), pp.C5-195-C5-206. <10.1051/jphyscol:1972515>. <jpa-00215117>

HAL Id: jpa-00215117
https://hal.archives-ouvertes.fr/jpa-00215117
Submitted on 1 Jan 1972

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. La base archivistique pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
HEAVY ION ACCELERATORS OF THE FUTURE

Ch. Schmelzer
GSI, Darmstadt, Germany

Résumé - Après avoir discuté les propriétés des faisceaux d'ions lourds, nous décrivons les moyens dont nous disposons avec les accélérateurs conventionnels. Nous discutons en outre l'état actuel et les développements futurs, les nouvelles sources d'ions, les accélérateurs supra-conducteurs et l'accélération collective.

Abstract - After a discussion of beam properties for heavy ion nuclear research, present possibilities of using conventional accelerating systems are described. The present status of future developments, new ion sources, superconducting accelerator structures and collective acceleration, is reviewed.

1. Introduction

The desire of nuclear physicists and chemists to use heavier and heavier projectiles has increased rapidly during the past few years. The papers read during this conference give not only an impressive demonstration of this tendency, but they also point out that experimental nuclear research with heavy projectiles opens new ways toward a deeper understanding of nuclear matter.

A new generation of particle accelerators specifically designed for the production of sufficiently energetic beams of heavy ions will, however, not only lend important services to nuclear research. The study of interactions of fast, heavy ions with matter opens new ways to solve quite different problems in numerous fields of natural philosophy. Besides that, several interesting technological applications can be envisaged.

Atomic physics is one of these fields. Beam foil spectroscopy allows the investigation of the electronic spectra of highly ionized atoms, as well as the determination of the life-times of the involved excited states under especially clear experimental conditions. This material may prove, for instance, valuable for theoretical astrophysics and stellar spectroscopy with extraterrestrial instruments. Spectra of atoms of very high atomic number can be simulated within the short time interval (about $10^{-19}$ s), during which two colliding heavy ions form one "molecular ion".

The high specific energy loss of heavy particles slowed down in condensed matter causes considerable radiation damage. Very heavy ions produce excitation energies up to a few $10^2$ eV/atom. Aside from possible applications in fundamental solid state research, the production of measurable changes of the macroscopic properties of material irradiated with heavy ions becomes possible in times that are orders of magnitude shorter than by irradiation with light particles. Thus the testing of, e.g., reactor materials can be speeded up considerably.

Finally, the high ionization density at the end of the track of a heavy ion stopped in condensed matter allows typical chemical reactions to occur, which are of particular interest in radiation biology and may eventually lead to applications in medical therapy.
This necessarily incomplete list of applications of energetic heavy ion beams may serve to demonstrate the breadth of what may be called heavy ion research and to show that the justification for constructing heavy ion accelerators rests not only on the demands of nuclear physicists and chemists.

2. Beam parameters

The following list of beam parameters and properties of a heavy ion accelerator is based on the needs for nuclear research but covers the (generally less severe) requirements for heavy ion experiments in many other fields as well.

The mass range should cover all elements with the possible exemption of the very light species \((A \approx 10\) to \(20\)), which already can be accelerated to useful energies by many existing machines.

The maximum specific energy, \(W/A\), should reach sufficiently far above the Coulomb barrier for reactions with the heaviest target elements, i.e.

\[
(W/A)_{\text{max}} \gtrsim 8 \text{ MeV}
\]

for the heaviest projectiles. For lighter particles \((A \approx 60)\), values about twice as large are desirable, e.g., for work in nuclear spectroscopy.

The energy must be continuously and – considering the narrow energy windows of many interesting heavy ion reactions – reproducibly variable. A lower limit of

\[
(W/A)_{\text{min}} \gtrsim 2 \text{ MeV}
\]

is desirable to stay sufficiently far below the Coulomb barrier, e.g., for the study of Coulomb excitation.

The primary energy resolution should correspond to the state of the art,

\[
W/\Delta W \gtrsim 200
\]

being a typical value. This statement deserves two comments. Firstly, it seems, as can be seen from inspecting Fig. 1, that the large specific energy loss of heavy ions makes high energy resolution unnecessary. Nevertheless, good energy resolution must be provided for experiments with lighter ions and/or extremely thin, e.g., gaseous, targets. The second comment concerns the term "primary" energy resolution. It refers in particular to radio frequency accelerators, where not the energy spread, but the distribution of particles in longitudinal phase space forms a correct measure of beam quality. As indicated in Fig. 2, the envelope of the particle distribution should be slender, because then the beam can be manipulated by de- or rebunching to appear at the target without loss of beam intensity either in shape b (good energy resolution and long micropulse) for coincidence experiments, or in

Fig. 1: Energy decrease of 10 MeV/nucleon ions of Zn, Sn and U within a Ni target. The shaded regions indicate the penetration depth, where the energy of the ions is close to the Coulomb barrier (1).

Fig. 2
shape a (larger energy spread and short pulse duration) for time-of-flight experiments. The efficient use of the latter case demands the highest technically possible "on/off" ratio of beam intensity.

Finally, particle currents of

\[ N \geq 10^{12} \text{ s}^{-1} \]

should be provided for the heaviest projectiles, and higher values are desirable for lighter particles.

The physical limitation of useful beam intensity is given by the power dissipation in the targets. Fig. 3 shows a rather extreme case. A 6 MeV/nucleon uranium beam irradiates 1 cm² of a 1 mg cm⁻² uranium target. The particle current is \( 1.2 \times 10^{12} \text{ s}^{-1} \), corresponding to a target dissipation of 10 Watts. With a continuous beam (curve b) the target equilibrium temperature is already very close to the melting point of uranium, whereas the instantaneous peak temperatures caused by a pulsed beam (curve a, 5 ms on, 15 ms off) are well above this value. The use of targets rotating in synchronism with the pulse frequency becomes essential (curves c,d).

That, nevertheless, higher beam intensities are desirable in some cases, e.g. for producing strongly collimated beams by throwing away a large fraction of the particles, may be illustrated by the following example. A 10 MeV/nucleon lead beam is scattered in a lead target. Seen under 45°, the angular distance between scattered projectiles leaving the target nucleus in the ground state and the first excited state (2.6 MeV) amounts only to roughly 1 mrad. A separation of the two scattering peaks thus demands a primary beam parallel within at least 0.3 mrad. (It should be noted that charge change processes occurring at the collimation diaphragms greatly help in producing clean, highly collimated beams, provided that the last defining aperture is followed by a suitable clearing field.)

3. The ideal heavy ion accelerator

The ideal heavy ion accelerator is shown schematically in the upper part of Fig. 4. The box at the right represents a conventional, variable energy accelerator. The essential part is the ion source S. It must produce sufficiently intense beams of ions of a charge-to-mass-number ratio which, over the entire range, must be

\[ q/A \geq 0.3 \]

Thus the desired specific energies can be obtained with a relatively moderate total accelerating voltage. With such an ideal ion source, many existing machines could be used for heavy ion work,

"doch die Verhältnisse, sie sind nicht so!" (3)
An inspection of Fig. 5 shows what can actually be expected from conventional arc ion sources, The velocity dependence of the mean charge after stripping is today sufficiently well known for the present purpose \(^4\). The results are presented in form of the two nonograms, Fig. 6 and Fig. 7, which are correct within about \(\pm 1\) to \(2\) charge units.

![Duoplasmatron](image)

**Fig. 5:** Performance of present arc sources for heavy ions.

The way out of this situation is to raise \(\zeta/A\) by stripping at elevated velocities. The accelerator then takes the form shown in the lower part of Fig. 4: a preaccelerator raises the energy, typically to \(1\) to \(2\) MeV/nucleon, where the ions are stripped in a gaseous or solid target. Values of \(\zeta/A\) up to 0.5 and more can be obtained by this procedure. The useful beam intensity, however, decreases. Typical relative yields for the most abundant charge state decrease from 50\% for N- to 15\% for U-ions.

![Nomogram](image)

**Fig. 6:** Nomogram for \(\zeta(\beta, Z)\) after stripping in gaseous targets \(^5\).

The superiority of foil strippers is impaired by intensity limitations. Stripping foils, typically of \(10^{-5}\) g cm\(^{-2}\), can hardly stand particle currents of very heavy ions \((A > 10^2)\) of more than \(10^{11}\) s\(^{-1}\). There is hope that this situation can be improved.

Summing up, it is not yet possible to produce beams of proper intensity and in sufficiently high charge states of high-Z atoms in ion sources that are suitable for accelerator purposes. Therefore, it is necessary to enhance \(\zeta\) by stripping. The "conventional" heavy ion accelerator thus becomes a combination of two accelerating systems separated...
by a stripper.

4. Conventional acceleration methods

Before discussing several typical combined heavy ion accelerators, a few more general points deserve mentioning.

The dependence of specific particle energy, \( \frac{W}{A} \), on the charge-to-mass ratio of the accelerated ions differs for different acceleration methods, as shown in Table 1.

The distinction between "common field" and "separate field" RF-Linacs in Table 1 deserves explanation. In common-field linacs (e.g. of the Alvarez type), the accelerating structure is embedded in an electromagnetic field common to all accelerating gaps. The length of the drift tubes determines the velocity profile along the beam path. In separate-field linacs, the accelerating gaps are excited individually, and by proper settings of phase and amplitude of the gap fields, the energy gain of the structure can be varied.

The last remark leads to the question of energy variation. Table 2 summarizes the different possibilities. An additional explanation is necessary in the case of common field linacs. There, energy variation is only possible by deforming the axial electric field (tilt) in such a way that at a certain axial position the particles drop out of synchronism and begin to drift. The disadvantage of this method is, besides needing rather

---

**TABLE 1**

Dependence on \( \frac{z}{A} \) of specific energy gain \( \frac{\Delta W}{A} \)

<table>
<thead>
<tr>
<th>Accelerating system</th>
<th>( \Delta W ) governed by</th>
<th>Spec. energy gain ( \frac{\Delta W}{A} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC</td>
<td>Voltage</td>
<td>( a \frac{z}{A} )</td>
</tr>
<tr>
<td>Separated field Linac</td>
<td>particle velocity</td>
<td>= constant</td>
</tr>
<tr>
<td>Common field Linac</td>
<td>Particle mag. rigidity</td>
<td>( a(\frac{z}{A})^2 )</td>
</tr>
<tr>
<td>Circular accelerators</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Fig. 7:** Nomogram for \( \zeta(\delta, z) \) after stripping in solid targets (5).
TABLE 2
Variation of particle energy

<table>
<thead>
<tr>
<th>Accelerating system</th>
<th>Parameters of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC</td>
<td>voltage</td>
</tr>
<tr>
<td>Separated field Linac</td>
<td>phase or voltage</td>
</tr>
<tr>
<td>(w = constant)</td>
<td>(ω = constant)</td>
</tr>
<tr>
<td>Common field linac</td>
<td>axial field distribution</td>
</tr>
<tr>
<td>(beam quality suffers)</td>
<td>(ω = constant)</td>
</tr>
<tr>
<td>Circular accelerators</td>
<td>Guide field and frequency</td>
</tr>
<tr>
<td></td>
<td>(K_m = constant)</td>
</tr>
</tbody>
</table>

tedious though reproducible adjustment, that the beam quality suffers and, in particular, the time structure more or less vanishes.

Vacuum requirements for heavy ion accelerators are more severe (by about one order of magnitude) than for machines accelerating light particles in order to minimize charge changes due to collisions of ions with residual gas atoms. The effect of charge-changing collisions during acceleration differs characteristically for the three major accelerating methods: For electrostatic machines, the particle of wrong charge simply gains a different energy. In RF-Linacs, it is further synchronously accelerated, and only the beam quality suffers somewhat. In circular machines, the center of the particle orbit after a charge change no longer coincides with the center of the guide field, and the particle is lost.

5. Typical heavy ion accelerator combinations

Several accelerator combinations, partly in operation or construction, partly in the state of proposals, are shown schematically in Fig. 8.

Combination 1 shows a linear accelerator of the HILAC-type. A typical example will be discussed in more detail at the end of this section.

Fig. 8: Typical heavy ion accelerator combinations. S = Ion source; L = RF Linac; St = Stripper; F = e/m-Filter; B = Buncher; h = Frequency multiplication.
The next two combinations use electrostatic machines as injectors. Tandem van-de-Graaff machines are shown, which in themselves can already be considered combined accelerators. In its present state of development, their use for heavy ion research is limited to experiments in the mass range \( A \approx 30 \). A Tandem, providing a 6 MeV/nucleon beam of uranium would not only need a terminal voltage of about 50 MV, but also two foil strippers, one in the terminal followed by a second in the accelerating column. Thus, the expected beam intensity will be low for very heavy ions. For uranium, the overall transmission turns out to be only a few percent. The construction of such a super-tandem may present considerable technical difficulties.

On the other hand, extending the energy and mass range of existing tandem facilities by RF post-accelerators is of considerable interest.

The combination shown in Fig. 8.2 uses an RF linear postaccelerator. A helical accelerating structure is shown. Using about fifteen sections each 1 m long, bromine ions can be accelerated to 5.5 MeV/nucleon. The expected particle currents are of the order of \( 10^{11} \text{ s}^{-1} \). The necessary mean RF power is about 300 kW, if the postaccelerator is pulsed with 25% duty cycle. An extension of the mass range of this combination much above \( A = 100 \) seems uneconomical, both for reasons of beam intensity and power consumption.

The combination in Fig. 8.3 represents another widely discussed solution. A split-sector, isochronous cyclotron replaces the linear postaccelerator of Fig. 8.2. Using a tandem with 20 MV terminal voltage, \( \zeta/A = 0.15 \) for the heaviest ions, which can be accelerated to 8 to 10 MeV/nucleon in a maximum guide field of approximately 16 KG. The maximum orbit radius will be about 3.5 m. The split-sector type allows placement of the stripper \( S_2 \) outside the cyclotron, which is of considerable advantage from an operational point of view. (In conventional cyclotrons, the stripper must be placed inside the machine, as indicated in Fig. 8.5)

As in the preceding example, double stripping leads to considerable intensity limitations for high-Z beams.

Thus, one comes to consider other injector systems, cyclotrons (Fig. 8.4) or linear accelerators (Fig. 8.5). In both cases, a single stripper is necessary and the overall transmission for heavy ions correspondingly larger. For reasons discussed below, a linac injector would appear preferable, were it not for the additional complications arising from the necessity of matching a constant-frequency injector to a variable-frequency post-accelerator (see also Table 2).

Size and cost of the postaccelerator depend, under otherwise equal circumstances, largely upon the charge-to-mass ratio \( \zeta/A \). After stripping increases with particle velocity. Hence, the mass dependence of specific energy \( (W/A) \) of the pre-accelerator becomes important. The full curves in Fig. 9 show the characteristic behavior of a

![Fig. 9: Dependence of maximum specific energy \( W/A \) on mass number \( A \) for different heavy ion machines (6). See text for details.](image-url)
Fig. 10: Layout of the UNILAC tandem (MP), a linear accelerator (CF-Linac) and a cyclotron (CY), based on realistic ion source properties (see Fig. 5) and, for the tandem, the stripper performance. Considering the slopes of these curves, the common field linac shows the best properties.

The dashed lines in Fig. 9 give typical values of the overall mass dependence of W/A for the first three examples of combined accelerators shown in Fig. 8. The decision as to which combination one may select depends, besides considerations of constructional and operating cost, mainly on the envisaged experimental program.

The accelerator combinations described so far appear to be realistic solutions for specific energies up to about 10 MeV/nucleon for uranium. For much higher energies, synchrotrons are by far the most economical postaccelerators (Fig. 8,6). The use of a fast cycling synchrotron with a correspondingly short beam path is advisable, and specific injection energies above about 5 MeV/nucleon should be used. Both facts help to reduce the vacuum requirements necessary for obtaining a good beam transmission.

The necessarily rather sketchy remarks made so far may deserve a few more detailed comments. The UNILAC, now under construction at Darmstadt, may serve as an example (Fig. 10).

The ion sources will be duoplasmatrons for A ≥ 80 and Penning sources for the heavier projectiles. Flexibility considerations and a certain pessimism with respect to source life-times led to the installation of two separate 320 kV DC injectors, each with space for two sources.

The beam transport system to the accelerator proper has a mass resolution of M/AM = 250 for a 10 cm mrad beam. This precaution is considered essential, since, contrary to cyclotrons, linear accelerators show poor separating properties.

The beam is then injected at 12 keV/nucleon into a chain of four Wideröe accelerators, all together 27 m long. The low particle velocity at injection (β = 0.005) dictates the low frequency of 27 MHz in the preaccelerator. The beam is accelerated to 1.4 MeV/nucleon and then enters the stripper region. Stripping is accomplished either by a transverse CO₂ jet or by foils, and a short helix
section serves to compensate for the energy loss in the strippers. A magnetic charge separator selects the desired charge state for further acceleration, and in addition allows the selection of a parasitic beam for experiments at low energy.

The following postaccelerator works at 108 MHz and consists of three main elements: a first Alvarez accelerator raising the specific energy to 3.8 MeV/nucleon, a second Alvarez going to 5.9 MeV/nucleon. Both Alvarez tanks are 29 m long. Finally, a 20 m long chain of twenty separately excited single gap cavities allow for continuous energy variation. For specific energies between 3.8 and 6.2 MeV/nucleon the second Alvarez stage is switched off with the exception of the central cell, which then serves as a rebuncher. If necessary, the lower energy limit can be extended to 1.8 MeV/nucleon by decelerating in the single gap structure.

With 2 MW mean RF power installed, 8.5 MeV/nucleon uranium ions are obtained in pulsed operation (macroscopic duty cycle of 25%, i.e. 8 MW pulse power) by using the gas stripper. With foil stripping, only 3.2 MW pulse power is necessary for the same energy, and 10.2 MeV/nucleon are reached with 5.5 MW pulse power. The dependence of obtainable specific energies for other elements is shown in Fig. 11.

6. Technological improvements

The conventional accelerating systems described above are pretty far from the "ideal" heavy ion machine discussed initially, both with respect to size, as well especially in the case of linear accelerators - as by considering the power consumption. The improvement of ion sources and the introduction of superconducting RF structures open very promising possibilities to improve this situation.

The main aim in producing sources for ions of higher charge than available today is to increase the containment time of the ions within the source in order to reach high charge states by stepwise ionization under intense electron bombardment. The EBIS (Electron Beam Ion Source) shown schematically in Fig. 12 may serve as a typical example. A strong electron beam (e.g. 3 keV, 10 A cm⁻²), focused by a solenoid, traverses the source and is collected at the electrode C. A set of auxiliary electrodes, 1 to 3, creates a potential well (a in Fig. 12) in which ions are trapped and ionized stepwise. After a containment time of the order 10⁻² s, the potential of electrode 3 is lowered, the well opened (b in Fig. 12) and the ions can be extracted by electrode E. With this type of source

![Fig. 12: EBIS source, after Septier (7).](image-url)
Donets\textsuperscript{8}) obtained beams of Au\textsuperscript{19+} with good intensity (10\textsuperscript{11} s\textsuperscript{-1}). Vacua below 10\textsuperscript{-8} Torr are necessary to obtain a sufficiently large ratio of recombination-to-containment-time. Work is in progress\textsuperscript{9}) to allow for continuous instead of pulsed extraction.

The second technological improvement aims at producing high accelerating fields at low power, using superconducting structure elements. The RF surface conductance of copper at room temperature is about 10\textsuperscript{-2} Ohms at 2 GHz, but drops to 10\textsuperscript{-8} Ohms for a niobium surface at 1.8 K. Thus, the RF power to produce a given accelerating field is reduced by six orders of magnitude and hence negligible compared to the power necessary to accelerate the particle. The consequent extreme beam loading in the superconducting case presents some problems, which, however, appear sufficiently understood to be mastered.

Work on superconducting structures for electron linacs began a decade ago at Stanford. The Karlsruhe Group concentrated a large part of their effort on "slow" accelerating structures which eventually will be suitable for heavy ion work\textsuperscript{10}). Reproducibility of the properties of superconducting resonators was solved by using niobium conductors covered by a thin film of niobium pentoxide.

For slow particles, the small dimensions of helix resonators make them especially suited for a superconducting structure. Superfluid helium, flowing through the hollow conductor, considerably simplifies the cooling problem. So far, axial field gradients at 17 MV/m have been obtained, and in a prototype accelerator, using a single helix about 40 cm in length, protons were accelerated from 750 to 1130 keV. To estimate this accomplishment, it should be remembered that the band width of the helix resonator is only a few Hz at 90 MHz resonance frequency. To overcome disturbing effects caused by mechanical vibrations as well as by ponderomotoric effects (the helix carries currents of several hundreds of amperes), an elaborate, fast servo-system had to be developed. The next step to master is to lock two and more accelerating elements in phase. When this problem, which is being studied in the meantime in several laboratories, is solved successfully, projects of superconducting heavy ion linear accelerators should be seriously considered. Although it is premature to predict actual construction cost of superconducting machines, the operating cost (including refrigeration) of a superconducting linac is certainly lower by a factor between five and ten compared to "warm" machines of equal performance.

7. Collective Acceleration

Through all the preceding discussions, the charge/mass problem went like a "red thread". The present inability to produce sufficiently large \( \zeta/A \) values for heavy ions complicates all conventional accelerating systems, all of which use external electric fields acting on individual charged particles. This \( \zeta/A \) difficulty could be overcome, as was shown in principle by Alfvén and Wernholm\textsuperscript{11}) two decades ago, if the accelerating field would act on a large assembly of electrons containing a small admixture of positive ions, such that the global charge-to-mass ratio of the assembly always stays close to that of a single electron. Since during acceleration all members of the assembly move with the same velocity, the energy of the ions

\[
W = w(M/m_0 \gamma),
\]

where \( w \) is the energy of the electrons, \( M \) the ionic, \( m \) the electronic rest mass and

\[
\gamma = (1-\beta^2)^{-1/2}.
\]

The main obstacle to producing stable assemblies which can be collectively accelerated was overcome by Veksler\textsuperscript{12}), whose concept of the relativistic electron ring rests on earlier work of Budker\textsuperscript{13}). Consider a ring of \( N_e \) electrons, moving with the velocity \( \beta \). Then the Coulomb repulsion felt by an electron is reduced by the factor \( 1-\beta^2/\gamma^2 \) due to the Lorentz attraction of the electron currents. The remaining repulsion can be compensated for by adding a number \( \zeta N_{ion} \) of positive charges. If
the ring is stabilized. The maximum electric field, the holding power, of the ring is proportional to \(1/\alpha\), \(\alpha\) being the circulating current, and the radius of the current thread. One of the methods of producing electron rings is sketched in Fig. 13. A short, very intensive burst of well-collimated, fast electrons is injected into a magnetic mirror field formed by two solenoids, thereby forming a relatively large ring. Then the magnetic field is rapidly raised (for 10 to 100 \(\mu\)s). The ring diameter and its thickness shrink, and at the same time the electrons gain further energy as in a Betatron. A short pulse of atoms is then injected, which are ionized by electron collision and stabilize the ring. Typical dimensions of rings compressed in this manner are 6 cm major and 0.2 cm minor diameter. With \(10^{13}\) circulating electrons and \(\gamma = 40\), the holding power is about 150 MeV/m. A slight axial asymmetry of the magnetic field allows the ring to be moved from the compressor into an axial field for acceleration. Besides axial electric fields, a constant, very slowly decreasing axial magnetic field (\(B = 10\) gauss) can be used for acceleration (Fig. 14). The energy used for the acceleration of the ring is taken from the energy of the circulating electrons. The ring dimensions thus increase, and the holding power falls correspondingly.

So far, several laboratories have produced compressed-electron rings, but only Sarantsev's group in Dubna succeeded in accelerating alpha-particles to 30 MeV by the magnetic acceleration method (14).

Peterson (15) has estimated that a magnetic acceleration field 1.7 m long is sufficient to accelerate \(10^9\) uranium ions trapped in an electron ring of the dimensions given above to 10 MeV/nucleon. The duration of the beam pulse is about \(10^{-10}\) s, and repetition rates of \(10^2\) s\(^{-1}\) appear possible.

Since the technique of collective acceleration of electron rings is still in an early phase of development, it appears premature to compare the possible performance of electron ring accelerators with that of more conventional machines. It appears that several years of research are necessary to prove the practical applicability of this brilliant new method.
REFERENCES

2) F. NICKEL and H. Ewald, to be published.
3) B. BRECHT, "Die Dreigroschenoper", Berlin (1928).
5) The nomograms were prepared by B. FRANZKE, GSI.
8) E.U. DONETS et al., Proc. 1st Int. Conf. on Ion Sources, Saclay, 635 (1969).
10) A. CITRON, private communication
11) H. ALFEN and O. WERNHOLM, Arkiv for Fysik 5, 175 (1952)
14) V.P. SARANTSEV et al., Dubna report JINR P9-5558 (1971).

DISCUSSION

M. Lefort (Orsay)

As Prof. Schmelzer said in his introduction, it would be very desirable to develop highly charged ion sources, since strippers won't ever be a good solution for high intensity beams of multicharged ions. At the present time, the more promising study corresponds to Donets's proposal. However it seems that the duty cycle is for the moment...very small. Since it is so important for the future of heavy ion machines, it would be very useful to organize a joint effort in Europe for developing new multicharged ion sources of Donets type.

J. Steyaert (Univ. de Louvain-la-Neuve)

Appearance of new accelerators produces much enthusiasm but up-grading of presently available ones is certainly an other way to go. What can CERN (European Organization of Nuclear Research) do for heavy-ion physicists as it is well known that to-day heavy-ion accelerator projects are at the limit of national budgets. Can we have heavy ions in PS and ISR?