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Important Atomic Physics Issues for Ion Beam Fusion

Roger O. Bangerter

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I. Introduction

The nearly endless variety of interesting and challenging problems makes physics research enjoyable. Most of us would choose to be physicists even if physics had no practical applications. However, physics does have practical applications. This workshop deals with one of those applications, namely ion beam fusion.

Not all interesting and challenging atomic physics questions are important for ion beam fusion. This paper suggests some questions that may be important for ion beam fusion. It also suggests some criteria for determining if a question is only interesting, or both interesting and important.

Importance is time dependent and, because of some restrictions on the flow of information, also country dependent. In the early days of ion beam fusion, it was important to determine if ion beam fusion made sense. Approximate answers and bounds on various parameters were required. Accurate, detailed answers were not needed.

Because of the efforts of many people attending this workshop, we now know that ion beam fusion does make some sense. We must still determine if ion beam fusion truly makes good sense. If it does make good sense, we must determine how to make it work. Accurate detailed answers are becoming increasingly important.

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II. Atomic Physics Issues

There are at least six areas of physics and engineering that require more work if ion beam fusion is to become a reality:

1. Accelerators
2. Beam transport and focusing
3. Beam-target interaction
4. Implosion and thermonuclear burn
5. Reactors
6. Target fabrication

At least five of these areas involve atomic physics.

Accelerator design requires accurate values of beam-beam and beam-gas charge exchange and ionization cross sections. Ion sources also rely on atomic physics.

Atomic physics is important for beam transport and focusing. Although heavy ions can be focused in a vacuum, it may not be desirable to do so. For light ions, the currents are too high for vacuum focusing; and gas is normally used to provide charge neutralization. Introduction of gas for either light or heavy ions raises a number of atomic physics questions relating to plasma formation, charge exchange, ionization, radiative processes, and knock-on electron production.

The beam-target interaction involves atomic physics. The two important questions are the range-energy relations and preheat production.

Atomic physics is involved in nearly all aspects of implosion systems. However, this is the area where the importance of questions is most strongly country dependent. In this paper we ignore issues specifically relating to implosions.

Finally, reactor design depends on atomic physics - particularly the design of gas filled reactors. The behavior of the first wall depends on the spectra of charged particles and photons reaching the wall. It is therefore necessary to calculate the spectra emitted from the target and to calculate the transport to the reactor wall.

Target fabrication involves chemistry and materials science. Although these sciences use the principles of atomic physics, target fabrication is perhaps the only one of the six areas that does not directly use much atomic physics.

Thus, we see that atomic physics is involved in nearly all aspects of ion beam fusion. However, the beam-target interaction, specifically range-energy physics, has received the most attention from the community represented at this workshop. International cooperation has been good; the work has been excellent; and most critics of ion beam fusion are now convinced that ion energy deposition is reasonably well understood. Some remaining problems are discussed in the next section.

III. The Beam-Target Interaction

Accurate information on the range-energy relation is not required if we are interested only in determining the feasibility of ion beam fusion. This conclusion follows from Fig. 1. Figure 1 shows the energy required to get gain 100 as a function of ion range. The curves in Fig. 1 are not universal since they are based on a particular type of target.

Nevertheless, the sensitivity of gain to ion range illustrated by these curves is typical of a large class of target designs. The curves were generated by varying the target dimensions to give good performance at a specified range. Based on these curves, it is evident that uncertainties in range of 20% (or more) do not substantially alter an assessment of the feasibility of ion beam fusion. However, the performance of a fixed target depends strongly on ion range. See Fig. 2. Thus, detailed target design does require accurate range information.

In summary it does seem important to complete the remaining work on range-energy physics. Effects of order 10% are probably important. Effects of order 1% may be interesting, but are probably not important.

The time dependence of the ion charge state and experiments are two areas where additional work is required.

One potentially important area of atomic physics has been largely ignored, i.e., the production of x-rays by both the beam and target ions. For some target designs, hard x-rays might produce bothersome preheat levels. As a general rule, preheat by some particular mechanism should be investigated if ~1% of the beam energy is involved. If $\lesssim$ 0.01% of the beam energy is involved, the effect may be interesting, but it is probably not important.

There are two other questions in beam-target interaction physics that should be answered more fully. Are there any anomalous effects (plasma instabilities, etc.) in low-density materials such as the target corona? Have any nuclear physics effects been overlooked that might be damaging in terms of preheat? These two questions involve plasma and nuclear physics as well as atomic physics. Perhaps a few experts in these areas should participate in the next workshop.

Finally, there is one relatively urgent issue that requires input from the atomic physics community. Test accelerators for ion beam fusion are being designed and/or built in several countries. It is important that the parameters of these accelerators be chosen to test the relevant physics issues.

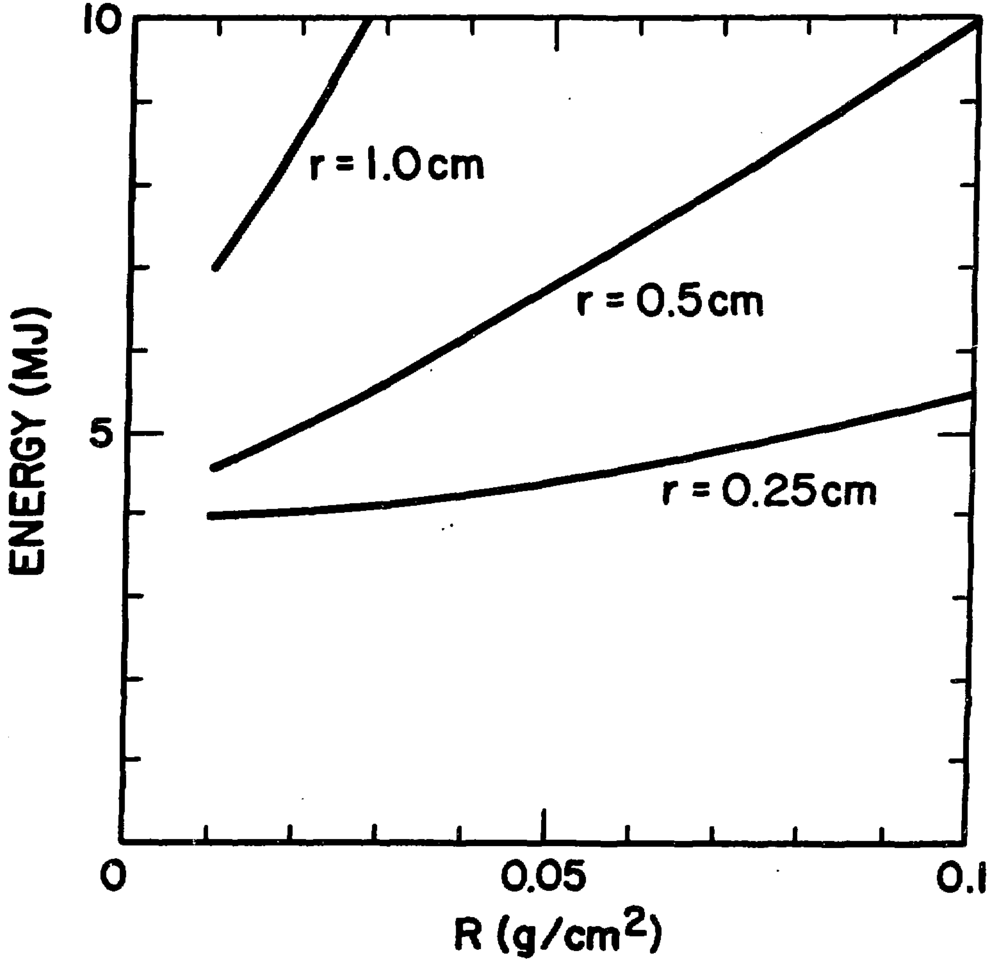
For example, in the U.S., we are planning to build an induction linac for heavy ion fusion studies. This accelerator and its associated experimental program are referred to as the High Temperature Experiment. We have adopted a number of design criteria for this machine. Those criteria relevant to the beam-target interaction are:

1. The machine should be able to heat a target to > 50 eV.
2. The beam plasma frequency should be at least a third of the beam plasma frequency of a full-scale fusion driver.

Comments on the necessity or sufficiency of these criteria would be valuable.

IV. Conclusions

Not all interesting atomic physics questions are necessarily important. We should attempt to choose research projects that are both interesting and important. Atomic physics is involved in nearly all aspects of ion beam fusion. To date most research has been focused on the beam-target interaction. This research has been necessary and successful, but it is now important to consider a wider variety of problems. In particular, input from atomic physicists is required to ensure that proposed accelerators address the truly relevant physics issues.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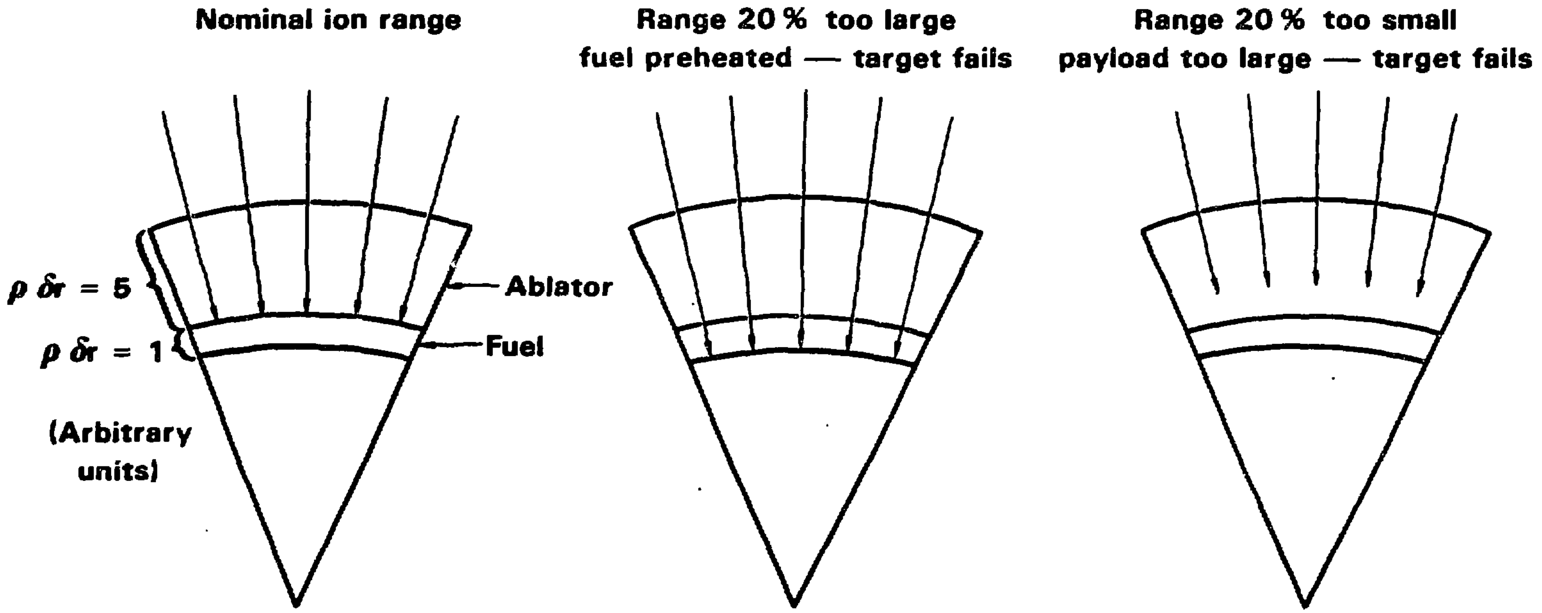

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Figure Captions

Figure 1

Energy required to achieve gain 100 as a function ion range for three different values of beam focal spot radius. The feasibility of ion beam fusion does not depend strongly on an accurate knowledge of ion range because the target dimensions can be varied to accommodate a given range.

Figure 2

For detailed target design, the range must be accurately known because a given target must be driven by ions of the appropriate range.