Thin Foils for Beam-Foil Spectroscopy

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Prepared for Presentation
4th International Conference
Nuclear Target Development Society
Argonne National Laboratory
September 29 to October 1, 1975
THIN FOILS FOR BEAM-FOIL SPECTROSCOPY*  

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Abstract

Two effects will be discussed. The first involves comparing the breakage of carbon foils (5 μg cm⁻²) under impact of focussed and non-focussed beams. Under defocussed beam conditions produced by x and y sweeping at frequencies of 1 kHz across the 25 mm² foil, breakage was reduced by a factor of 5 to 10. Secondly, we discuss the effect of tilting thin foils relative to incoming heavy-ion beams. The final surface interactions change drastically giving rise to changes in the excited heavy ion products.

*Work performed under the auspices of the U. S. Energy Research and Development Administration.
This will be mostly a short qualitative description of what we do with thin carbon foils and what beam-foil spectroscopy is and so I'll probably end up with more questions directed to you than solutions to any big problems. We initially started out using the thin carbon foils just to do some experiments but we ended up more interested in what we can do about understanding the foils themselves. I hope that some of you have some good answers for me.

First of all, I'll just briefly describe what beam-foil spectroscopy is. It involves foils, of course. Figure 1 shows a heavy ion beam (e.g. Ni⁺) coming from the left, impinging on a thin carbon foil generally 4—5 µg/cm² thick. The experiments at Argonne use ion beams between 1 and 4 MeV giving us lifetimes of the foils in the ion beam of an hour or so. I'll go into the lifetime problem a little more later. In front of the beam we have a beam defining aperture so that theoretically the beam does not impinge at the foil holder. I think this gives us somewhat better lifetime characteristics. A Faraday cup measures the beam current after the foil. The beam picks up and loses electrons in the foil and comes out of the foil as a neutral X, or as X⁺, X⁴⁺, X⁷⁺, etc. and this is really a function of the ion-beam energy. In general, say, we have 2-MeV nitrogen going through the foil. Coming out of it will be N⁷⁺ and there will be some N⁴⁺ and N⁺, almost no neutrals and there will be a little 4⁺ and 5⁺. We should note that this X⁺ is not in its ground state but has picked up a little extra energy. Thus one of the electrons on the singly-charged nitrogen has slightly
more energy and loses this energy by decaying and giving off some light. It decays down to the ground state of each ion eventually, emitting light of various wavelengths. Since we are spectroscopists we're interested primarily in this light, which is analyzed with a spectrometer and electronic detection. In fact, with a microamp of beam through a carbon foil at these energies you can put your eye next to the chamber and you can see a lot of light. Nitrogen, for example, is a blue light. In fig. 2 there is a rather nice example of a singly-charged lithium beam. If you look carefully you can see that the light is blue initially and then it's green further on down. In fact the blue light comes from doubly-charged lithium and it gives off the light rather quickly. It takes a few nanoseconds for the light to travel down beam and we can say that this blue light decays within a fraction of a nanosecond. It goes back down to the ground state of the doubly-charged lithium ion whereas the green light decays very slowly. There is quite a complex process going on which produces this light in the beam. But it's all initiated by the foil. We look at various positions along this beam and measure how fast the light decays.

The foils are about 5 μg/cm² and in the Argonne arrangement we have 1/4" diameter with a pre-aperture of 5/16 of an inch. We focus the beam through this aperture without a foil into the Faraday cup and then we apply what we call rasters, horizontal and vertical, to apply a high frequency electric field somewhere before the bending magnet. It sweeps this beam spot so then we get a rather
uniform current density within our foil area. Since, as Yntema pointed out, the current density is quite important in determining how long these foils live, we make a nice uniform spot size so we can increase the lifetime accordingly, proportional to the areas we use, defined by the front aperture and a uniform current density going through the foil. We don't heat the foils. The foil holder is a rotatable disc which is rotated from outside the vacuum system with 23 such foils on it. Rather than heat the foils we rely on being able to replace them very easily.

Perhaps it is very obvious that just defocussing the beam really improves our experimental system. Defocus whenever possible is the moral to this result.

The second point was that just recently we tried tilting these foils. This is where we ran into the question of what these foils are made of and how can we improve the system. The beam defines the Z axis and we tilt the foil and again look at the light of the beam after the foil, in the direction k. We find that the light yield changes, although we had thought the interaction with the beam involved picking up and losing electrons in the target and nothing should happen when we tilt it. For example, the polarization of this light was very different. We place a polarizer along the light axis, rotate the polarizer to see a large change in the polarization. More interestingly, we found that we induced circular polarization. Thus, if we looked
along the X axis we'd see that the light was circularly polarized. This meant that atom was rotating relative to this X axis. This meant there was some interaction of the surface, equivalent to some sort of torque which is pulling it. Sometimes it's rotating the other way, depending on what atom we look at. Previous to this we thought the interesting interaction we were looking at was something that was going on inside the carbon and since all carbon foils are equivalent then this is just a bulk type of interaction. It's much more difficult when we get to the surface because as you all know, there's a big question whether this is carbon at the surface? It may well be carbon inside, but what do we have on the surface? In the last talk we heard from Jan Yntema that there is carbon buildup or some sort of buildup. The foil gets thicker in general. So, if this surface is continually changing these effects like the polarization of the lights should change too. We run vastly different vacuum systems, we run for hours, and to within the 1% type measurement we see no change at all in our polarized light.

If we have a foil of a certain thickness that we start out with and we admit that it's building up impurities on the surface, the question is, on which surface does it build up? I haven't heard an answer to that question although many people have opinions on it. If it were being built up on the first surface it would make sense that we would see no change in the light yield. But given that it's building up on the final surface and we see no change, could it be that the atoms, say the big hydrocarbons which are being deposited on this, are they being broken up by the ion beam very rapidly so that they become free carbon atoms and hydrogen atoms, etc.?
If they were, we'd end up still with carbon and we wouldn't see any change in the polarization. I know there are some electron measurements at the University of Chicago that show that under electron beams these big hydrocarbons break up in a matter of seconds or so. Whether they do with ion beams, I don't know. So I'd be very interested in any answers on this problem. There is a whole series of questions we can ask. Is it clean or is it dirty, is it rough or is it smooth? And we saw from those nice pictures of Jan Yntema's that the surface structure really changes as you impinge with the ion beam. For example, the pictures that he showed are very similar to what we've seen at the Dynamitron -- the foil starts out quite smooth to the eye, but after a little while you see large scale crinkles. But then, just before it breaks (maybe half an hour or so before it breaks) it looks shiny and smooth. At Laval University, Quebec, they find that for carbon beams at 6 MeV beam energies, they run experiments for a couple of hours until the foil gets smooth and then they make their real measurement and then the foil breaks right after that. We had some comments about heating the foil. There is some work I think which hasn't been published apparently by Kay at the University of Canterbury in England who's also tried heating the carbon foil and he measures a thickness of the foil at various times just by looking at the light profile and estimating the foil thickness; Kay finds that at low temperature the foil gets thicker. He has a normal vacuum of 10^{-6} Torr. As he heats up the foil to about 500^\circ it thickening process gets less and less and then if he goes over 500^\circ up to 1000^\circ it starts getting thinner in time. So it seems to me that this optimum
lifetime of the foil is the point where there is no additional thickness buildup in the target.

There are a couple of other things I'll just quickly mention. One is that we've tried some experiments using sandwich foils. For example, carbon on one side and aluminum on the other. Figure 3 shows the ratio of the light yield from He\(^+\) to He\(^++\) beam for different foils. The open circles correspond to 70-keV beam energy. If we look at this ratio for a Copper + Carbon sandwich, with carbon on the down beam side, and then look at this ratio when we reverse it for carbon + copper with copper on the down beam side, we get a different number for this ratio. It's not too different for copper and carbon nor for silver and carbon, but if you try aluminum and carbon and carbon and aluminum there is a difference of a factor of 2 in this ratio. This suggests that the interaction we are looking at depends on what material the ion beam sees last. We're still very puzzled by this result because this was a very poor vacuum, \(10^{-5}\) Torr and we certainly had impurities on the surface. This would say that there is some bulk effect in these interactions. What I wanted to mention here was that after running these sandwich foils, in the beam, if we didn't break them, quite frequently there would be no carbon left on them. For example, the aluminum foil would be just a pure aluminum foil. The carbon would peel off. Maybe this is one way to produce self-supporting targets!
There is just one other set of experiments which we do which concern the target which I thought someone else was going to mention but I'll mention it. We also try to replace this foil with a thin single gold crystal, of 500 Å thickness or so. We align this crystal so that its principal axis are across the beam and then we look at the light yield from the beam as a function of tilting the single thin crystal. We see changes in the light yield. The important thing here is that they have to be very thin because otherwise, say with a 1-MeV helium beam if we want a very definite spatial resolution a very definite velocity we have to have an order of 500 to 1000 Å thick, otherwise it loses a considerable fraction of its energy in the target. These thin gold crystals are made here, I guess in several places right now, but Jim Worthington who is here can discuss their manufacture in more detail.
Figure Captions

Fig. 1. Beam-foil experimental arrangement.

Fig. 2. Decay of a 700 keV Li$^+$ beam excited in a thin carbon foil.
(The dots represent the blue light which decays rapidly; the vertical bars represent the green light which goes through a maximum about 2 cm from the foil and then decays slowly.)

Fig. 3. Ratio of light yield for a He II transition and a He I transition for incident He$^+$ beams on sandwich foils.
monoenergetic ion beam

FIG. 1

ion beam

monochromator

Faraday Cup

to monitoring circuit

Coupling Lens

Window

To photon Counter

Entrance Slit

Detector

Exit Slit

Scanning Monochromator
FIG. 3