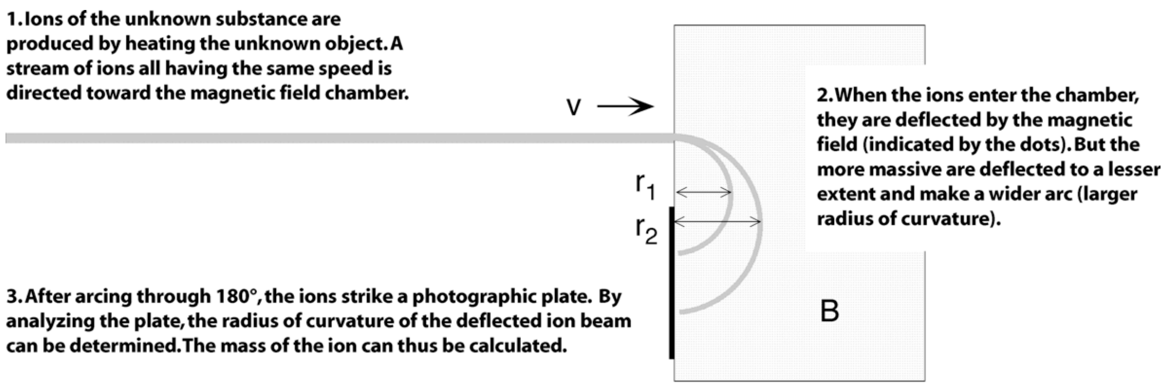
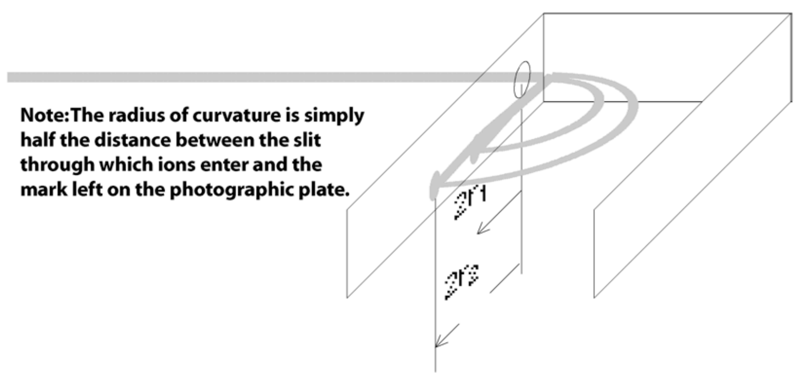
PhyzGuide: The Mass Spectrometer

SORTING OUT IONS

Suppose you've got a chunk of something, but you don't know what it is. You could perform some quantitative analysis (chemistry) experiments to figure it out. You could also use a **mass spectrometer** to aid in your detective work. A mass spectrometer allows the sorting of ions (slightly charged atoms or molecules). Its operation is based on two basic principles. First, that moving charged particles are deflected by magnetic fields. Second, that the amount of deflection depends on, among other things, the mass of the charged particle. It works like this:





LET'S GET ANALYTICAL

The big mystery here is the mass *m* of the ions in the unknown stuff. We can control (or we at least know) the values of the incoming ion charge *q*, and speed *v*, as well as the magnetic field strength *B*.

The *magnetic force* on an ion once it enters the field is	$F = qvB$
The force needed to keep anything in *uniform circular motion* is	$F = mv^2/r$
The *magnetic force* deflects each ion into a *circular* path, so	$qvB = mv^2/r$
The **mass** of the unknown ion is therefore	$m = qBr/v$

WORKING BACKWARDS

The mass spectrometer is a dandy application of basic physics, but let us probe a bit deeper. How do you get ions to move at a given speed into the magnetic chamber of the spectrometer in the first place? There are at least two ways.

1. THE ION GUN

Since the ions are charged, they respond to electric fields. The ions can be accelerated through strong electric fields created by large potentials. The ions gain kinetic energy equal to the potential energy they lose as they fall through the potential difference.

Since *potential difference* is defined as $V = PE/q$

The *kinetic energy* gained by the ions is $KE_{gained} = PE_{lost} = qV$

Since, by definition, $KE = {}^{1}/2\ mv^2$

it follows that the **speed** gained by the ions is $v = \sqrt{(2qV/m)}$

But if the **speed** gained by the ions *depends* on the mass of the ions, can we still use the spectrometer to *determine* the **mass** of the ions? Let's see...

The *mass* of an unknown ion was supposed to be $m = qBr/v$

and the *speed* of the incoming ions is $v = \sqrt{(2qV/m)}$

Therefore, $m = qBr/\sqrt{(2qV/m)}$

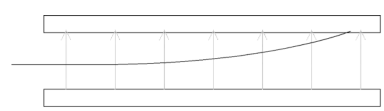
A bit of algebra yields an expression for the ion **mass** $m = qB2r2/2V$

2. THE VELOCITY SELECTOR

The second way of ensuring that ions have the right speed when they enter the mass spectrometer is by using a velocity selector. This is a very cool device. It's a little box that allows ions with a specific speed to pass right through but captures ions with other speeds and stops them cold: sort of a "Wrong-Speed Ion Hotel"—off-speed ions check in, but they never check out!

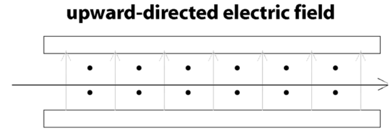
When the unknown object is heated, it gives off ions with many different speeds. For the mass spectrometer to do its thing, all entering ions must have the same speed.

Suppose positively charged ions traveled through an electric field *E*. They would be deflected as shown.



upward-directed electric field

But suppose a magnetic field *B'* were also applied in such a way as to oppose the effect of the electric field. Under the right conditions, the ions would pass straight through!



upward-directed electric field E coupled with an outward-directed magnetic field B'.

The right conditions occur when the electric force is balanced by the magnetic force.

The *electric* force is $F = qE$ *

The *magnetic* force is $F = qvB'$ †

The *electric* and *magnetic* forces are balanced when $qE = qvB'$

Which means the strength of the electric field is $E = vB'$

Ions will pass through undeflected only if their **speed** is $v = E/B'$

**Note that electric force* does not *depend on ion speed.*

†Note that magnetic force does *depend on ion speed.*

Ions with other speeds will be deflected and will not escape the selector.