TRIUMF

PHYSICS IN ACTION

Lesson Workbook by Philip Freeman and Marcello Pavan

Electromagnetism and Circular Motion in a Cyclotron

ANSWER KEY

Worksheet 1.1 Finding the Ionization Energy of H

1) 8.25×10^{-8} N inward
2) 2.19×10^{6} m/s
3) 2.18×10^{-18} J
4) -4.37×10^{-18} J
5) -2.18×10^{-18} J
6) 2.18×10^{-18} J

Worksheet 1.2 Estimating the Ionization Energy of H^-

1) 3.7×10^{-9} N inward
2) 9.2×10^{-10} N outward
3) 2.8×10^{-9} N inward
4) 8.7×10^{5} m/s
5) 3.46×10^{-19} J
6) -9.24×10^{-19} J
7) $+4.62 \times 10^{-19}$ J
8) -4.62×10^{-19} J
9) -1.16×10^{-19} J
10) 1.16×10^{-19} J

Worksheet 2.1 Finding the Initial Speed of the H^- Ions

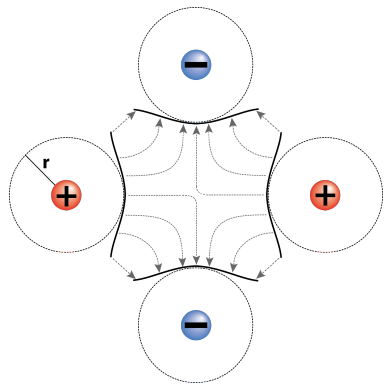
1) 1.45×10^{-22} J
2) 416 m/s
3) 0.00014%
4) 7.59×10^{6} m/s
5) 2.5 %

Worksheet 2.2 Getting the Beam to the Cyclotron

1) 1.32×10^{-5} s
2) 8.51×10^{-10} m
3) 6.59×10^{-10} s
4) -3.95×10^{-12} C
5) 9.12×10^{-16} N, repelling
6) 5.46×10^{11} m/s^2
7) 47 m
8) 7.91×10^{-10} C/m
9) 5700 N/C
10) 9.12×10^{-16} N

Worksheet 2.3 Electrostatic Focusing

1)



2) 2.78×10^{-8} C

3) $F_A = 3.17 \times 10^{-14}$ N↓
$F_{A'} = 3.17 \times 10^{-14}$ N↑
$F_B = 3.17 \times 10^{-14}$ N←
$F_{B'} = 3.17 \times 10^{-14}$ N→

4) 1.90×10^{13} m/s^2

5) 1.98×10^{-8} s

6) 3.75×10^{5} m/s

7) 2.83°

8) 0.30 m

Worksheet 3.1 Electrostatic Beam Steering

1) 1.51×10^{14} m/s^2 inward

2) 2.52×10^{-13} N inward

3) 1.57×10^{6} N/C outward

4) 5.98×10^{5} V

5) $\Delta V = \dfrac{m a_c d}{q}$

6) 5.98×10^{5} V

Worksheet 4.1 Circular Motion in a Magnetic Field - The Cyclotron

1) 3.64×10^{-13} N

2) 2.18×10^{14} m/s^2

3) 0.264 m

4) $r = \dfrac{mv}{qB}$

5) 2.19×10^{-7} s

6) 4.81×10^{-14} J

7) 2.98×10^{-14} J

8) 7.79×10^{-14} J

9) 9.66×10^{6} m/s

10) 0.336 m

11) 2.19×10^{-7} s

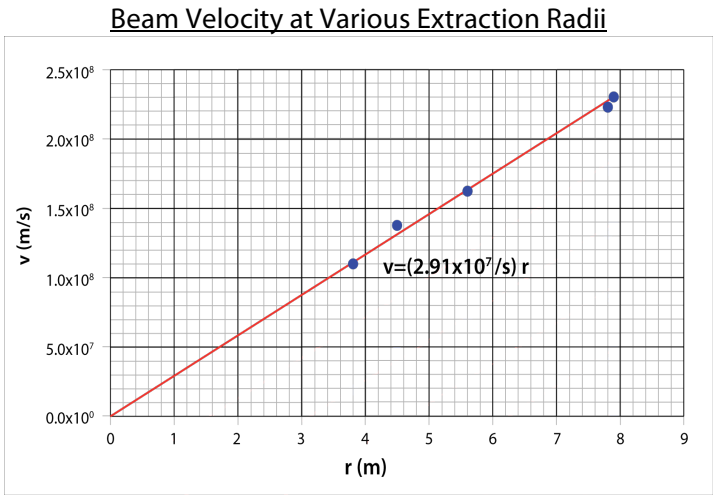
12) $T = \dfrac{2\pi m}{qB}$

13) 4.57×10^{6} Hz

14) $f = \dfrac{qB}{2\pi m}$

Worksheet 4.2 Finding the Cyclotron Frequency from Experimental Data

1)



2) approximately 2.9×10^{7} /s

3) 4.6×10^{6} Hz

Worksheet 5.1 Electrostatic Steering

1) 3.85×10^{15} m/s^2

2) 6.42×10^{-12} N

3) 4.01×10^{7} V/m

4) 1.52×10^{6} V

Worksheet 5.2 Electromagnetic Steering

1) 0.40 T

Worksheet 5.3 Designing a Steering Magnet

1) 1.59×10^{4} A

2) 3.18×10^{4} coils

3) 1.11×10^{5} m

Addendum: TRIUMF's Preferred Solution

1) 189 A

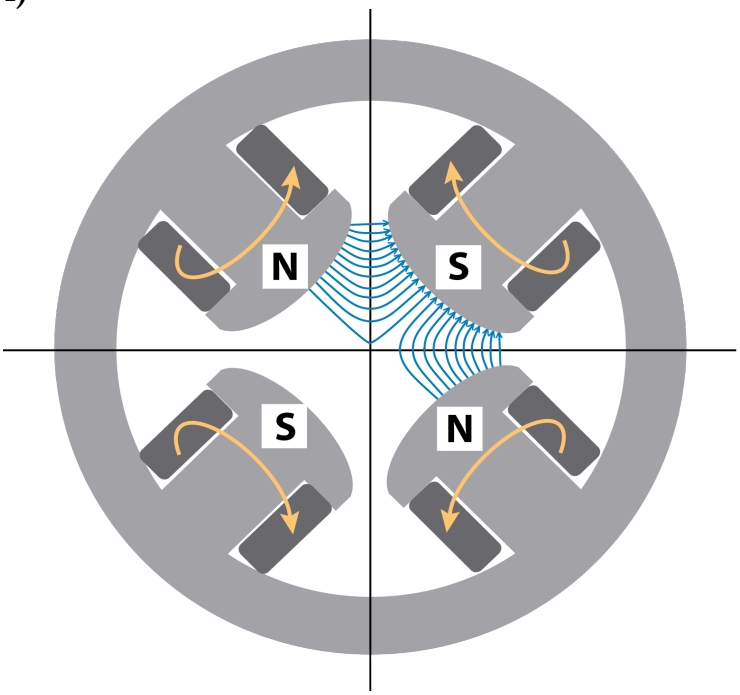
2) 0.061 Ω

3) 2200 W

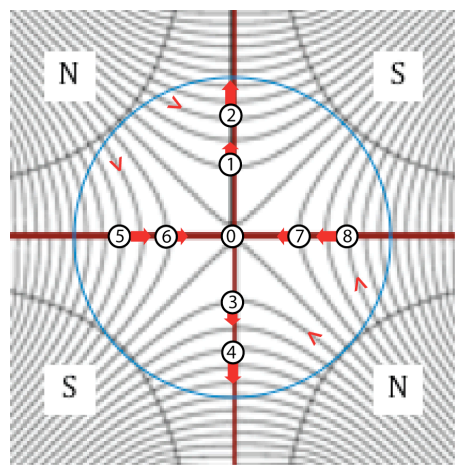
4) 13 g/s [13 mL/s]

Worksheet 5.4 Magnetic Field Focusing, Quadrupoles

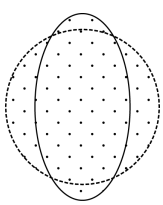
1)



2) + 3)



4)



5)

Protons that are first focused then defocused begin far from the centre, so a large force pushes them inward. When they are defocused by the next magnet, they begin nearer the centre, so a smaller force pushes them out. The inward push is bigger in effect than the outward push. On the other hand protons that are first defocused then focused begin nearer the centre, so the outward force is small, then when they are focused they have reached a point further from the centre due to the defocusing, and the inward force is bigger. Thus in this case too the focusing effect is greater than the defocusing effect.

Worksheet 6.0 Preliminary Exercise: Beam Filtering

1) 6.53×10^{-15} J

2) 6.53×10^{-15} J

3) 9.91×10^{5} m/s

4) 7.01×10^{5} m/s

5) 4.09×10^{-14} N

6) 3.08×10^{-12} m/s^2

7) 0.319 m

8) 4.22×10^{-14} N

9) 0.371 T

Worksheet 6.1 Beam Filtering

1) $E_P = q\Delta V$

2) $E_K = \frac{1}{2} mv^2$

3) Same

4) $v = \sqrt{2\Delta V \frac{q}{m}}$

5) $F_{mag} = qvB$

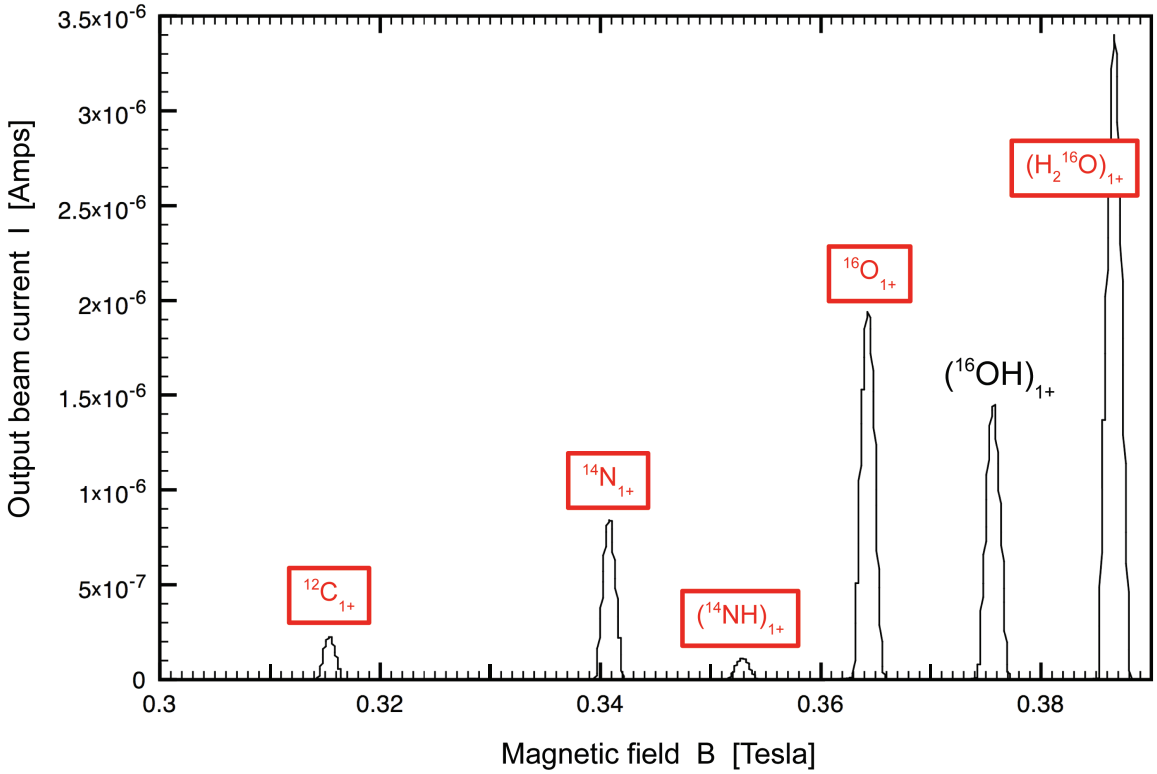
6) $F_{ion} = m\frac{v^2}{r}$

7) $r = \frac{mv}{qB}$

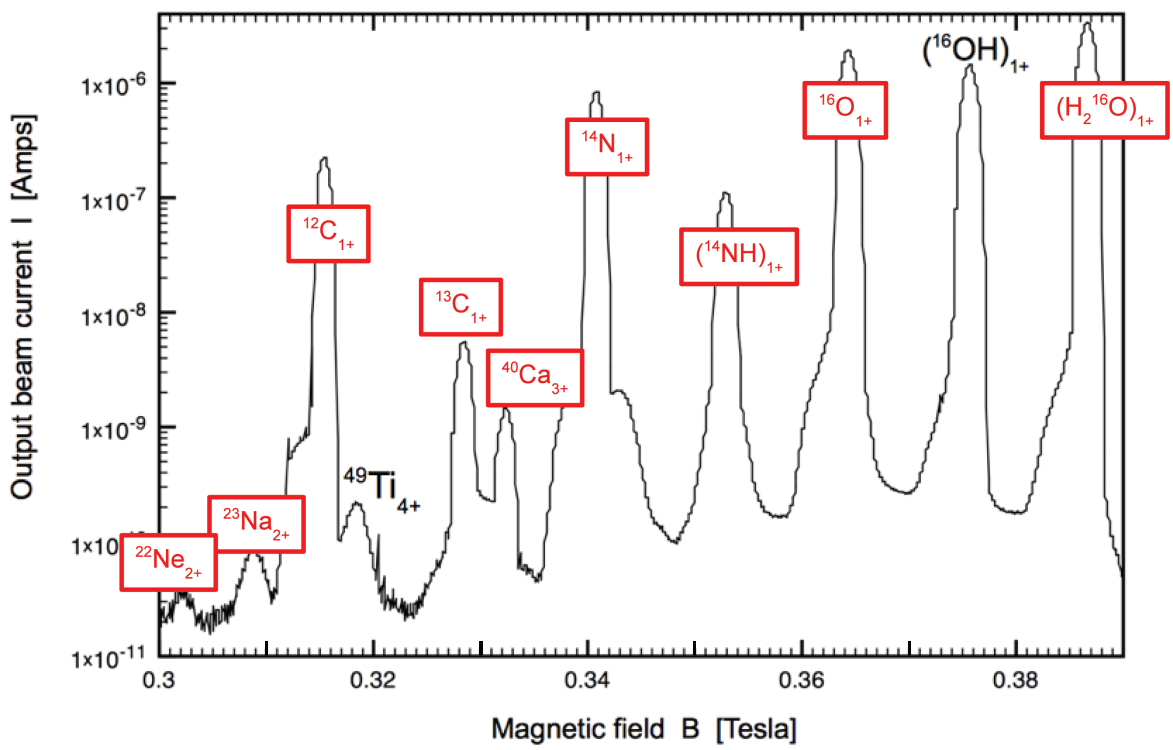
8) $r = \sqrt{\frac{2\Delta V}{B^2}\frac{m}{q}}$

9) $\frac{m}{q} = \frac{r^2 B^2}{2\Delta V}$

Worksheet 6.2 Identify Isotopes in Stable Isotope Mass Spectrum from TRIUMF



Worksheet 6.3 Challenging: Closer Look at Sample Isotope Mass Spectrum



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