MAKING TRACKS II: BUBBLE CHAMBER
TEACHER NOTES

DESCRIPTION

Students can "make" tracks in the sense of experiencing, analyzing, and understanding the tracks that particles make in cloud chambers and bubble chambers. These are old technologies. Current experimental particle physicists use complex detectors that handle the much higher rates of events and data from modern accelerators. However, cloud chambers and bubble chambers are uniquely visual, giving students a direct view of tracks that particles produce in a medium. This provides direct evidence that particles are passing around and through us all the time.

In Making Tracks I, students look at cloud chambers to see particle tracks appear and disappear before their eyes. Then, in Making Tracks II, they examine bubble chamber events to discover the behaviors and properties of particles. (The bubble chamber portion is based on the teacher materials for the PBS Nova program, *The Elegant Universe: Einstein's Dream*.)

STANDARDS ADDRESSED

Next Generation Science Standards

- Science Practices
  1. Asking questions
  2. Developing and using models
  4. Analyzing and interpreting data
  6. Constructing explanations
  7. Engaging in argument from evidence
- Disciplinary Core Ideas – Physical Science
  - PS1.A: Structure and Properties of Matter
  - PS2.B: Types of Interactions
  - PS3.B: Conservation of Energy and Energy Transfer
- Crosscutting Concepts
  1. Patterns
  2. Cause and effect: Mechanism and explanation
  3. Scale, proportion, and quantity

Common Core Literacy Standards

- Reading
  - 9-12.4 Determine the meaning of symbols, key terms . . .
  - 9-12.7 Translate quantitative or technical information . . .

Common Core Mathematics Standards

- MP7. Look for and make use of structure.

IB Physics Standard 7: The Structure of Matter

- Aim 1: The research that deals with the fundamental structure of matter is international in nature and is a challenging and stimulating adventure for those who take part.

ENDURING UNDERSTANDING

Indirect evidence provides data to study phenomena that cannot be directly observed.

Learning Objectives

As a result of this activity, students will be able to:

- Identify particle tracks in a bubble chamber.
- Predict the electric charge of a particle in a bubble chamber from its motion in a magnetic field.
- Apply conservation of electric charge to explain the shapes of tracks from particle decays.
- Use conservation of momentum to infer the existence of "hidden" particle tracks.

Prior Knowledge

Students should be able to:

- Use the Lorentz force that determines the direction of electrically charged particles moving through a magnetic field.
- Use the right-hand rule to determine the electric charge of the particle.

Background Material

About bubble chambers:

- CERN Document at http://cern.ch/go/fM9L
- Videos:
  - Bubble Chambers and Particle Detectors at http://cern.ch/go/qn6L
  - Grade 12 University Physics Bubble Chamber Basics at http://cern.ch/go/69B7
  - Visualising Antimatter with Frank Close at http://cern.ch/go/d7TJ

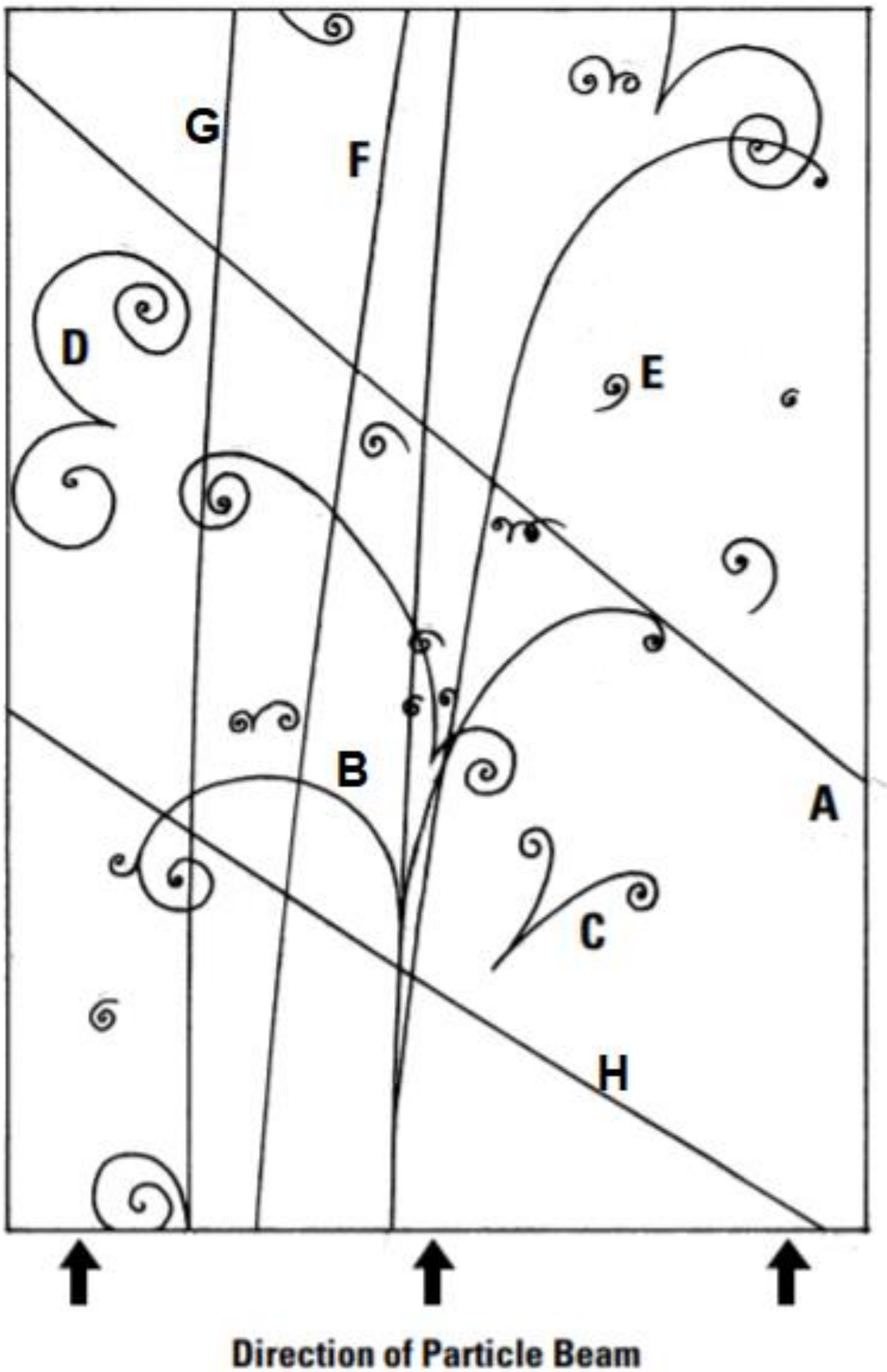
Resources

1. Prep materials:
   - 1.1. Seeing the Invisible at http://cern.ch/go/Xr9q
   - 1.2. Wikipedia article at http://cern.ch/go/7vRZ
   - 1.3. Optional: videos above in Background Material section
2. Original NOVA activity:
   - 2.1. Website, https://to.pbs.org/2Xzec8m
   - 2.2. Bubble Chamber Basics at http://cern.ch/go/RM6n
   - 2.3. Tracking Particle Paths at http://cern.ch/go/L7Jt

Implementation

When preparing for this activity, students should study Resource 1.1 and Resource 1.2. The videos in Resource 1.3 "give away" a lot, so you may want delay showing the videos until after the activity.

This image from the student guide:



Discuss the "What do we know?" section of the student guide, which contains this information:

1. The image is a replica of a photograph taken of a volume inside a bubble chamber. It appears planar because the photograph is two-dimensional.
2. As shown, the region is exposed to a beam of particles. Assume the beam particles have positive electric charge.
3. There is a uniform magnetic field in the bubble chamber. Looking at the plane of the bubble chamber image, the uniform magnetic field is perpendicular to the plane and pointed away from the observer, into the page. The paths of electrically charged particles are curved in the magnetic field. The radius of curvature depends on the magnetic field as well as the momentum and electric charge of the particle. The direction of curvature also depends on the electric charge.
4. Neutral (electrically uncharged) particles leave no tracks.
5. Electrically charged particles can radiate photons that have neither mass nor electric charge.
6. Particles lose energy as they interact with the medium in the bubble chamber.
7. In particle interactions, electric charge and momentum are conserved. Always.

Next, students should work in groups of 3–5. Each group should answer these questions, found in the student guide. Possible answers appear in italics.

1. Tracks A, F, G, and H go across the whole image. Are they straight? Why or why not? Which of these would most likely be particles from the beam? Why?
    - *Tracks A, F, G, and H hardly curve and are not absorbed, so they seem to high energy like a beam particle. However, only track F and track G are aligned with the beam direction, so they are beam particle candidates. Track A and track H are clearly far from the beam direction so they may not be beam particles. Track A and track H could be cosmic ray muons, which can come from multiple directions at high energies as indicated by the straight paths. Muons are very penetrating particles, so they can easily go all the way across the bubble chamber. In summary, track A and track H are most likely cosmic ray muons and track F and track G are most likely beam particles.*
2. Look at tracks B. Why do they curve? Can you figure out their electric charge? (Hint: The beam particles are positive.) We will come back to tracks B again later.
    - *Tracks B most likely curve due to the magnetic field. Track F and track G curve slightly clockwise. If the beam particles are positive and track F and track G are from the beam, then particles which curve anti-clockwise would have to be of negative electric charge. This is the case for tracks B. Since tracks B travels anti-clockwise, particle tracks B must have a negative electric charge [Using the right-hand rule, the beam is directed towards the top of the page, the magnetic field is directed into the page, using the right-hand rule, particles with positive electric charge travel in a clockwise direction.]*
3. There are two tracks at C. Why do they curve in opposite directions? Why do their curves get smaller and smaller? These two tracks come from the decay or transformation of one particle into two. What is the electric charge of the parent particle? What can the particle be?
    - *Based on the discussion of #2, we can say that they have opposite electric charge. Recall that particles lose energy, which is transferred to boil the bubble chamber medium and make the track. Therefore, momentum also decreases as they travel in the bubble chamber medium. What happens to the radius of curvature as the momentum increases? Decreases? If the momentum decreases, the radius of curvature will get smaller.*

4. Do tracks D follow the pattern of any of the tracks you have analyzed?
    - *Tracks D are like tracks C.*
5. Make a claim about why tracks C and tracks D just appear without an incoming track.
    - *Since the parent particle makes no track and it decays into particles of opposite electric charge, we have good evidence that it must be neutral. A photon fits the bill nicely.*
6. Use what you have learned so far to speculate on the nature of track E.
    - *Track E is funny. A photon may have caused this, as in tracks C and tracks D, but it could not have simply transformed because the one track has one electric charge. The track for E shows a negative electric charge. It is possible that the photon knocked a negative particle out of an atom in the medium. If that negatively charged particle is an electron, then track E is an example of the Compton effect, an advanced topic for future study.*
7. This is a challenge question: Let's go back to tracks B. How do you explain that "blossom" at the end?
    - *There may not be a clear answer. One possibility is that the particle with positive electric charge in turn transforms. Consider all options that obey the rules. A good extension would be to arrange a teleconference with one or more physicists to discuss this question.*

End the lesson with a class discussion of the student questions. Each group can report out and the class can reconcile the competing answers.

ASSESSMENT

Lead your class in a discussion of the claims you can make from the data. Encourage your students to provide evidence and reasoning for their claims.