DRAFT MAKING TRACKS II: BUBBLE CHAMBER DRAFT
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, now mostly supplanted in experimental particle physics with complex detectors that can handle the much higher rates of events and data from modern accelerators. However, they are uniquely visual, giving students a view of tracks that particles directly produce in a medium, as opposed to the admittedly amazing digital reproductions of events produced by special software.

In Making Tracks I, students will first look at cloud chambers for the experience seeing particle tracks appear and disappear before their eyes. Then, in Making Tracks II, they will examine bubble chamber events to discover the behaviors of particles.

The bubble chamber portions of this activity are 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
  5. Using mathematics and computational thinking
  6. Constructing explanations
  7. Engaging in argument from evidence
  8. Obtaining, evaluating, and communicating information
- 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

- MP2. Reason abstractly and quantitatively
- MP6. Attend to precision.

IB Physics Standard 7: The Structure of Matter

Aim 4: particle physics involves the analysis and evaluation of very large amounts of data
Standard 7.3.4: Apply the Einstein mass-energy equivalence relationship

ENDURING UNDERSTANDING

Particles are really real.

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 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 will know and be able to:

- Use the Lorentz Force that determines the direction of charged particles moving through a magnetic field
- Use the right-hand rule to determine the (positive or negative) charge of the particle.

BACKGROUND MATERIAL

About Bubble Chambers:

- Wikipedia, https://bit.ly/2XZIVdt
- CERN Document, https://bit.ly/2XzkIfk

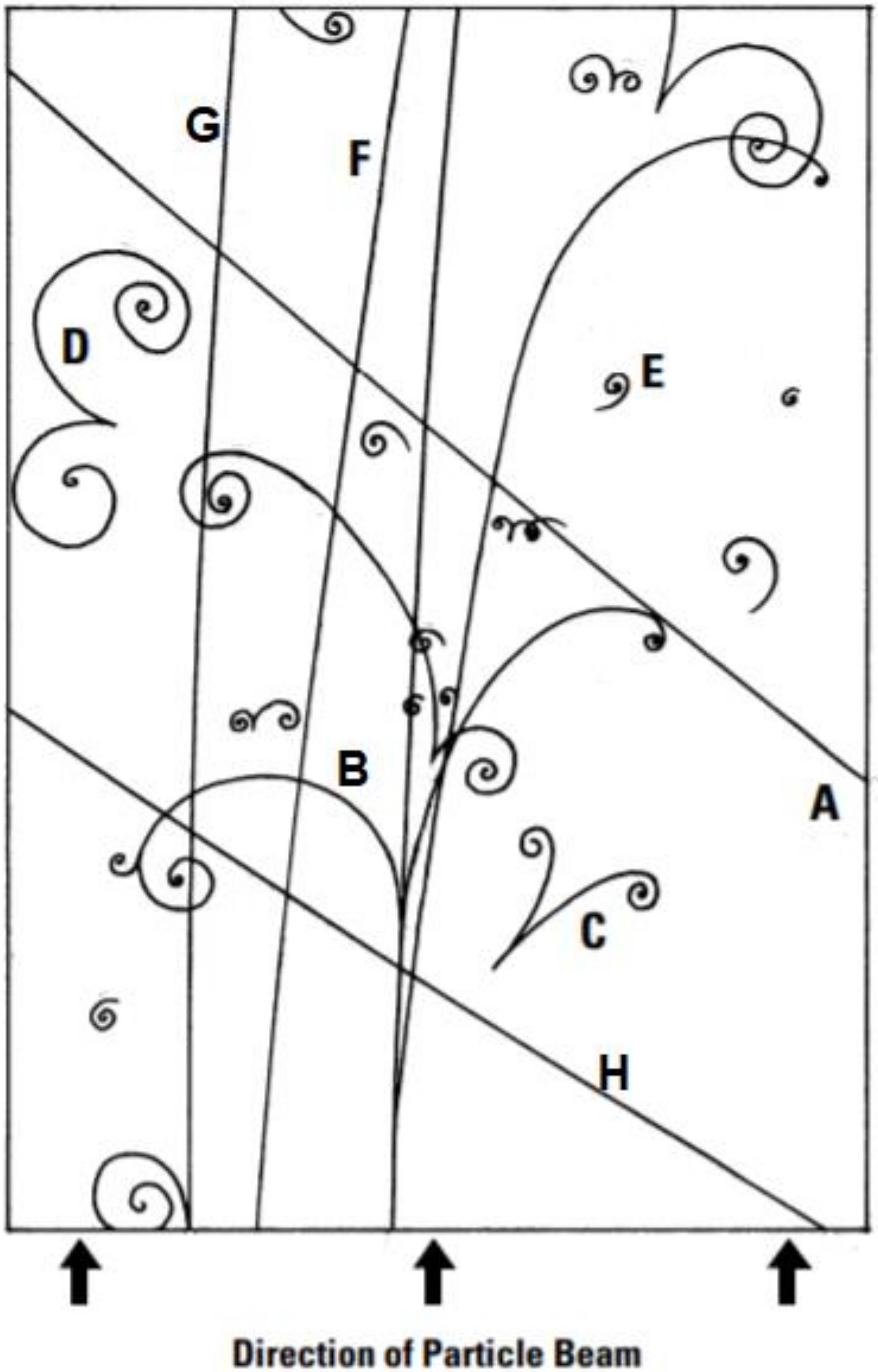
RESOURCES

1. Prep materials:
   1.1. Seeing the Invisible, https://bit.ly/370Gn2P
   1.2. Bubble Chambers and Particle Detectors (A-Level Physics video), https://bit.ly/304p3st
   1.3. TBD
2. Original NOVA activity:
   2.1. Website, https://to.pbs.org/2Xzec8m
   2.2. Bubble Chamber Basics, https://bit.ly/2XxPmFI
   2.3. Tracking Particle Paths, https://bit.ly/3gScGFU

IMPLEMENTATION

Students should prepare for this activity by examining Resource 1.1 if they had not already done so for Making Tracks 1 and either Resource 1.2 or Resource 1.3. These will give students the background understanding that will help them with the rest of the activity.

Students will aim at examining this image from the Student Guide:


G
F
D
E
B
A
C
H
Direction of Particle Beam

Go over 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 on the inside of 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 perpendicular to the plane of the image. The paths of charged particles are curved in a magnetic field. The radius of curvature depends on the magnetic field as well the momentum and charge of the particle. The direction of curvature also depends on the charge. How does each affect the path? How do we know?
4. Neutral (electrically uncharged) particles leave no tracks.
5. Charged particles can radiate photons, which have neither mass nor charge.
6. Particles lose energy as they interact with the medium in the bubble chamber.
7. In particle interactions, charge is conserved and momentum is conserved. Always.

Next, students should work in groups of 3-5. Each group should answer these questions, found in the Student Guide:

1. Can tracks F and G be from beam particles? Are they straight? Why or why not?
2. Tracks A and H look like F and G but are in a very different direction. Why? What might they be?
3. Look at track B. Why does it curve? Can you figure out its electric charge? (Hint: the beam particles are positive.) We will come back to B again later.
4. 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 (transformation) of one particle into two. What is the charge the parent particle? What can it be?
5. Explain D and E.
6. Let's go back to B. How do you explain that "blossom" at the end?

The final phase is a discussion of the questions in which you as the teacher can synthesize the student answers to reveal a little more physics. Here is how the discussion can be aimed:

1. The evidence shows that they go in the right direction and that, since they hardly curve and are not absorbed, they are high energy like a beam particle. Is that enough evidence? Do we have reason to say we have a good working hypothesis?
2. They are clearly far from the beam direction so maybe they are not beam particles. They go all the way across undeflected so they must have high energy. One candidate can be cosmic ray muons, which can come from multiple directions at fairly high energies. And muons are very penetrating particles, so they can easily go all the way across the bubble chamber.
3. B most likely curves due to the magnetic field. One can suggest that tracks F and G curve slightly clockwise. If the beam particles are positive and F and G are from the beam, then particles which curve anti-clockwise would have to be of negative electric charge. This is the case for B.
4. Based on the discussion of #3, we can say that they are of opposite charge. Recall that particles lose energy and therefore momentum as they travel in the bubble chamber medium. What happens to the radius of curvature as the momentum increases? Decreases? Since the parent particle makes no track and it decays into particles of opposite charge, we have good evidence that it must be neutral. A photon fits the bill nicely.
5. D is like C. E is funny. A photon may have caused this, as in C and D, but it could not have simply transformed, because the one track has one charge. Which? Negative, yes? Maybe the

photon knocked a negative particle out of an atom in the medium. An electron? [If so, this is called the Compton Effect.]

Assessment

Assessment can be based in the answers to the questions turned in by each team as well as by participation in group discussion.