Electric Potential

Derivatives and Integrals Series

Instructor's Guide

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Developed by the Teaching and Learning Laboratory at MIT
for the Singapore University of Technology and Design

Introduction

When to Use this Video

- In Phys 201, before Lecture 9 or as a review for Exam 1. Because this video works best when students can converse with each other, it should be used in class or in a discussion section rather than being assigned for homework.
- To get the most out of this video, students should know how to obtain the electric field from the electric potential mathematically. They will also be expected to draw electric equipotential surfaces and field vectors while watching the video.

Key Information

Duration: 12:45
Narrator: Prof. John McGreevy
Materials Needed:
• Paper
• Pencil/pen

Learning Objectives

After watching this video students will:

- Have a clearer picture of the electric field and electric potential.
- Be able to describe electrical breakdown in terms of the electric field or electric potential.

Motivation

- Students have difficulty with the concepts of electric field and electric potential, especially moving from one viewpoint to the other or appreciating the similarities and differences between the concepts. This video directly addresses similarities and differences in the two ideas and connections between their graphical representations.
- Students who have difficulty with rate-of-change ideas often retain that difficulty across multiple disciplines. By addressing issues related to the derivative in this context we hope to build a more complete understanding of the rate-of-change concept across many contexts.

Student Experience

It is highly recommended that the video is paused when prompted so that students are able to attempt the activities on their own and then check their solutions against the video.

During the video, students will:

- Recall different aspects of the electric field and electric potential.
- Discuss electrical breakdown in terms of both the electric field and the electric potential.
- Draw electric field vectors and equipotential lines in a way that uses and reinforces the relationship between them.

Video Highlights

This table outlines a collection of activities and important ideas from the video.

Time	Feature	Comments
1:20	Review	Students use a brainstorm as a memory check at 1:55 before a conceptual description of the field and potential. Next are some typical visualizations (level curves, field plots) and a mathematical description of the relationship between V and E.
4:42	Electrical breakdown introduced	
4:57	Clip from Boston Museum of Science	This clip shows the world's largest air-insulated Van de Graaff generator in action. The clip is followed by a definition of breakdown potential and an explanation of how it works.
8:14	Drawing equipotential surfaces and field vectors	Students draw these two using the generator as their subject. The video then walks students through the answer.
11:00	Potential or field?	This small segment addresses the common use of the terminology "breakdown potential".

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Video Summary

This video begins with a review of electric field and electric potential, focusing on their similarities and differences and the way they are most commonly represented. A video clip from the Boston Museum of Science's Theatre of Electricity helps to transition into a discussion of electrical breakdown, which is described in detail. Students are asked to consider the role of the field and/or the potential in creating a spark during electrical breakdown.

Phys 201 Materials

Pre-Video Materials

When appropriate, this guide is accompanied by additional materials to aid in the delivery of some of the following activities and discussions.

1. Drawing Lines (Appendix A1)

This clicker question probes for basic misunderstandings and confusion in electric field and potential concepts. Students who choose 1 but not 2 (or vice versa) may believe that there is a preferred, required, or "standard" orientation for capacitors. Students who choose 5 or 6, or who ask whether V_0 is positive or negative, may not have read the question correctly or may have field lines and equipotential lines reversed in their head.

2. Charge Distribution (Appendix A2)

The most defensible answer combination here is 2 and 6.

While 1 is clearly wrong, 3 is inaccurate in a less obvious way. The electric field can be determined from the charge configuration, but the potential can be changed by an arbitrary constant. Students often forget that the reference level for electric potential is an arbitrary value and must be either given in the problem or set explicitly while solving it. Setting the potential to zero at an infinite distance from a charge is typical, but not required, and so one cannot definitively say that the potential is zero at point P.

Some students may choose 5 if they accidentally use a $1/r^2$ dependance for the potential rather than $1/r$. This is another good place to explicitly pull apart field and potential concepts.

For the students who chose 6 initially, it is important to probe for *why*. "Impossible to know" too easily becomes "I don't know" in students' minds.

Post-Video Materials

1. Equipotential Lines (Appendix A3)

This clicker question asks students to determine the force based on an arrangement of equipotential lines. The most defensible answer is location 2. Some students may also choose 4, which may or may not be at a local extremum – its position at the edge of the diagram makes it difficult to say for sure. Location 1 is a poor choice as there is a slight but noticeable divergence of the equipotential lines at that point. Location 3 is very tempting, but it is difficult to say for certain whether the features on the diagram are all peaks, all valleys, or a mixture of both. Students who realize this may choose 6.

This question can lead into a discussion of stable vs. non-stable equilibria, or into a follow-up question asking where the force would be strongest. Asking students how they would clarify the diagram can also be fruitful.

2. Field Lines (Appendix A4)

This question is in some ways a reversal of the previous one: it asks students to determine the value of the electric potential based on a field line diagram. Answer 6 is the most defensible, as the potential can be increased or decreased by an arbitrary constant without affecting the electric field. Some students may choose location 1, which has a low field but not necessarily a low value for the potential. Others may choose location 4, looking for a location sufficiently far from the existing charges.

A demonstration with the electric field visualization tools listed in the Going Further section will show that location 3 is actually the most likely choice if the potential is set to zero at an infinite distance from the charges. This is fairly difficult to predict from the field lines.

3. Minimum Distance (Appendix A5)

This unexpected phenomenon is known as Paschen's Law. Imagine that a spark is created between a pair of electrodes, through an avalanche of electrons (as described in the video). When electrons can leap from one electrode to another without colliding with other air molecules, they do not yield a spark. As the gas pressure and the distance decrease, the mean free path of the electrons becomes comparable to the distance between the electrodes, and a spark becomes less likely.

A more complete description of Paschen's Law can be found in a variety of sources; the original paper (in German) is in the references.

Additional Resources

Going Further

Students interested in further visual representations of the electric field and electric potential can find many sources online. Some of the better simulations as of the time of this writing are listed below.

- Electric Field Applet:
  http://www.cco.caltech.edu/~phys1/java/phys1/EField/EField.html
- 3D Electrostatic Field:
  http://www.falstad.com/vector3de/
- Visualization of an Electrostatic Field:
  http://profs.etsmtl.ca/mmcguffin/research/electrostatic/applet1/main.html
- Electric Field Hockey:
  http://phet.colorado.edu/en/simulation/electric-hockey

References

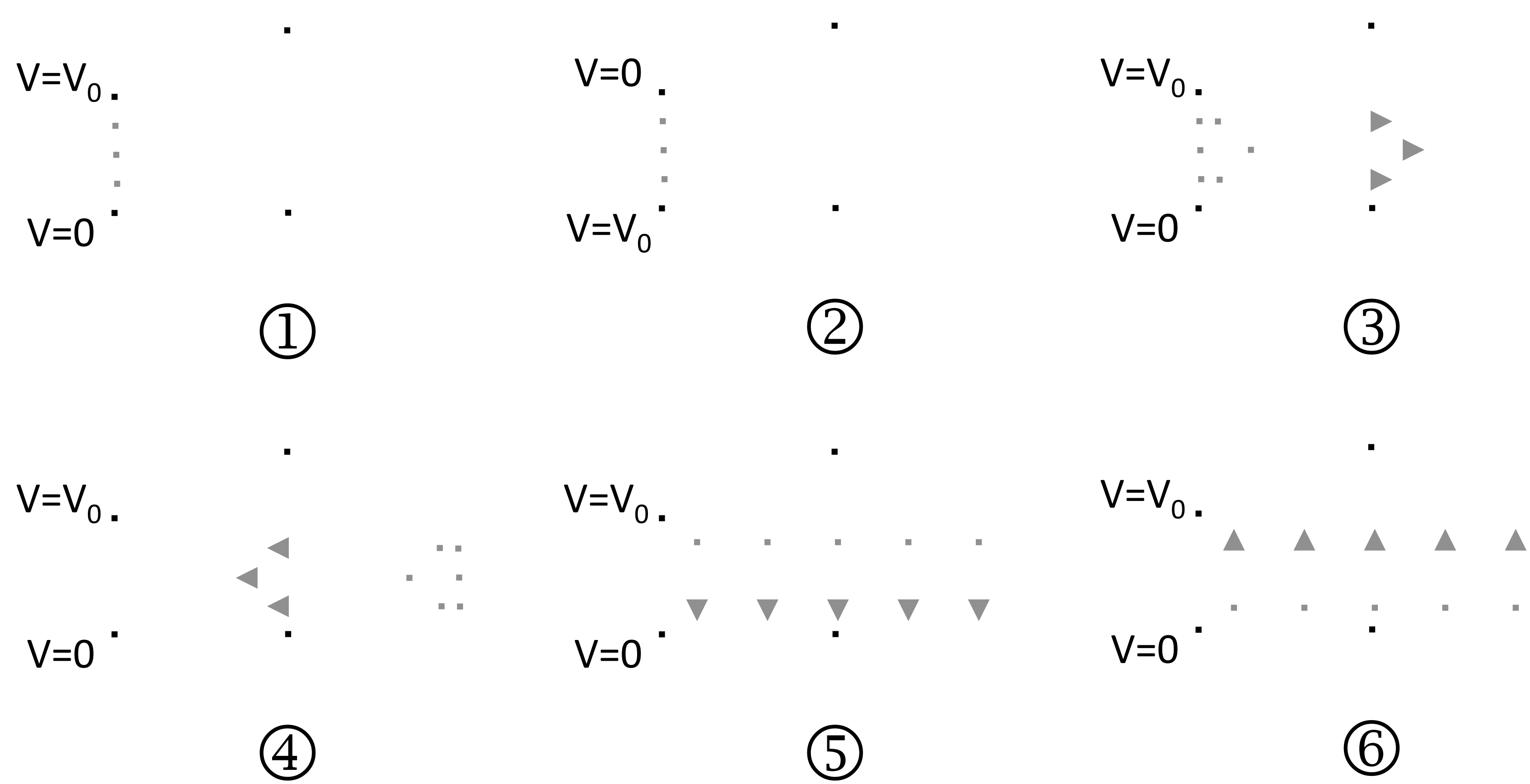
The references below focus on upper-level students' difficulties in visualizing EM fields and identifying problem-solving strategies.

- Chasteen, S., & Pollock, S. (2009, July 29-30). A Research-Based Approach to Assessing Student Learning Issues in Upper-Division Electricity & Magnetism. *2009 Physics Education Research Conference Proceedings,* part of the *AIP Conference Proceedings series, 1179.* Ann Arbor, Michigan. Retrieved February 6, 2012, from http://www.compadre.org/Repository/document/ServeFile.cfm?ID=9892&DocID=1524
- Törnkvist, S., Pettersson, K. A., & Tranströmer, G. (1993). Confusion by representation: On student's comprehension of the electric field concept. *American Journal of Physics, 61*(4), 335-338
- McMillan, C., & Swadener, M. (1991). Novice use of qualitative versus quantitative problem solving in electrostatics. *Journal of Research in Science Teaching, 28*(8) 661-670
- Ferguson-Hessler, M., and de Jong, T. (1987). On the quality of knowledge in the field of electricity and magnetism. *American Journal of Physics, 55*(6), 492-497
- Maloney, D., O'Kuma, T., Hieggelke, C., & van Heuvelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. *American Journal of Physics, 69*(S1), S12-23

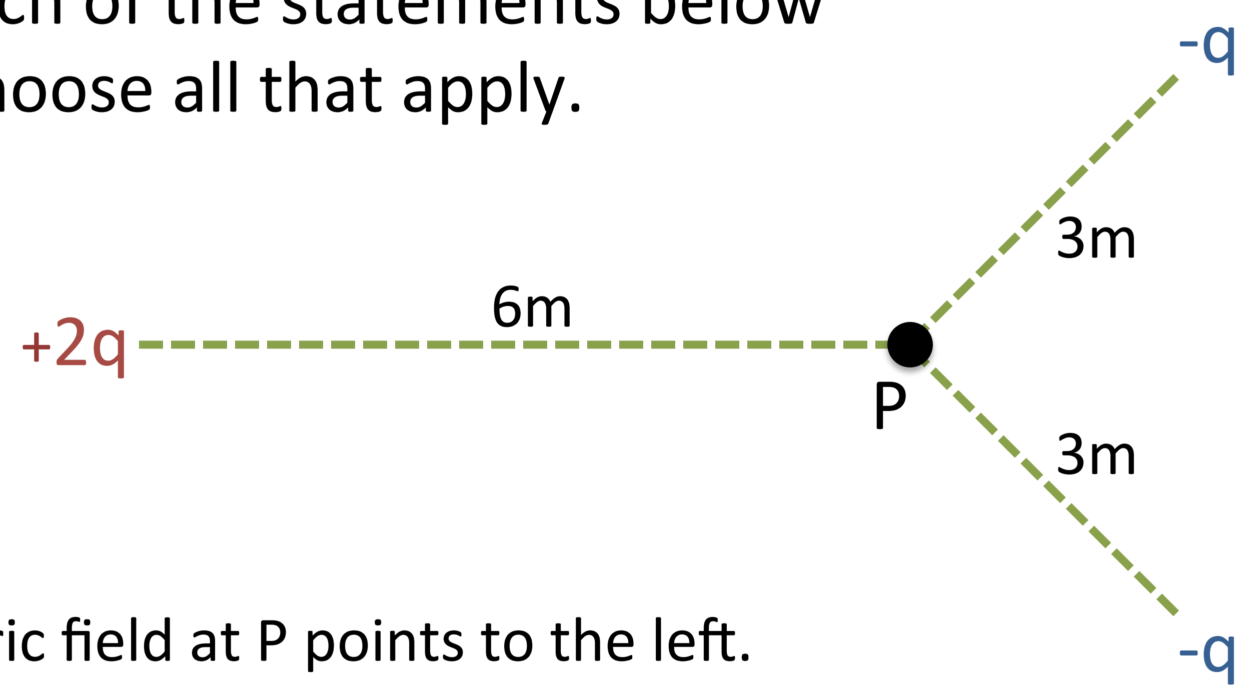
This is Paschen's original paper on the phenomen described in post-video problem #3 (see page A5). The reference below is in the original German.

- Paschen, F. (1889). Ueber die zum Funkenübergang in Luft, Wasserstoff und Kohlensäure bei verschiedenen Drucken erforderliche Potentialdifferenz. *Annalen der Physik 273*(5), 69–75.

The following diagrams show the equipotential lines inside a capacitor charged as shown. Which diagrams are incorrect? Choose all that apply.

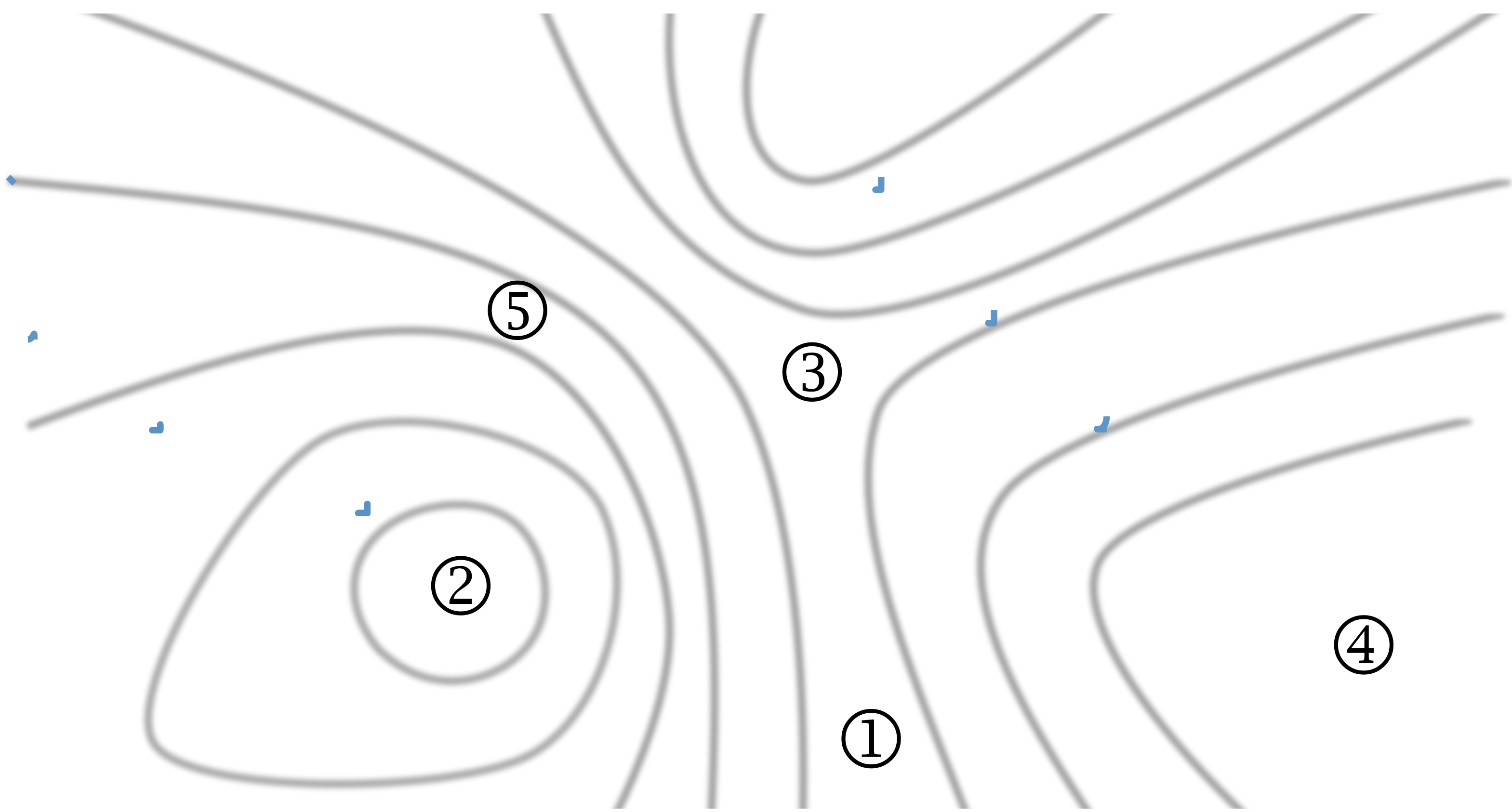


Three point charges are arranged around a point P, with charges and distances as shown. Which of the statements below are true? Choose all that apply.



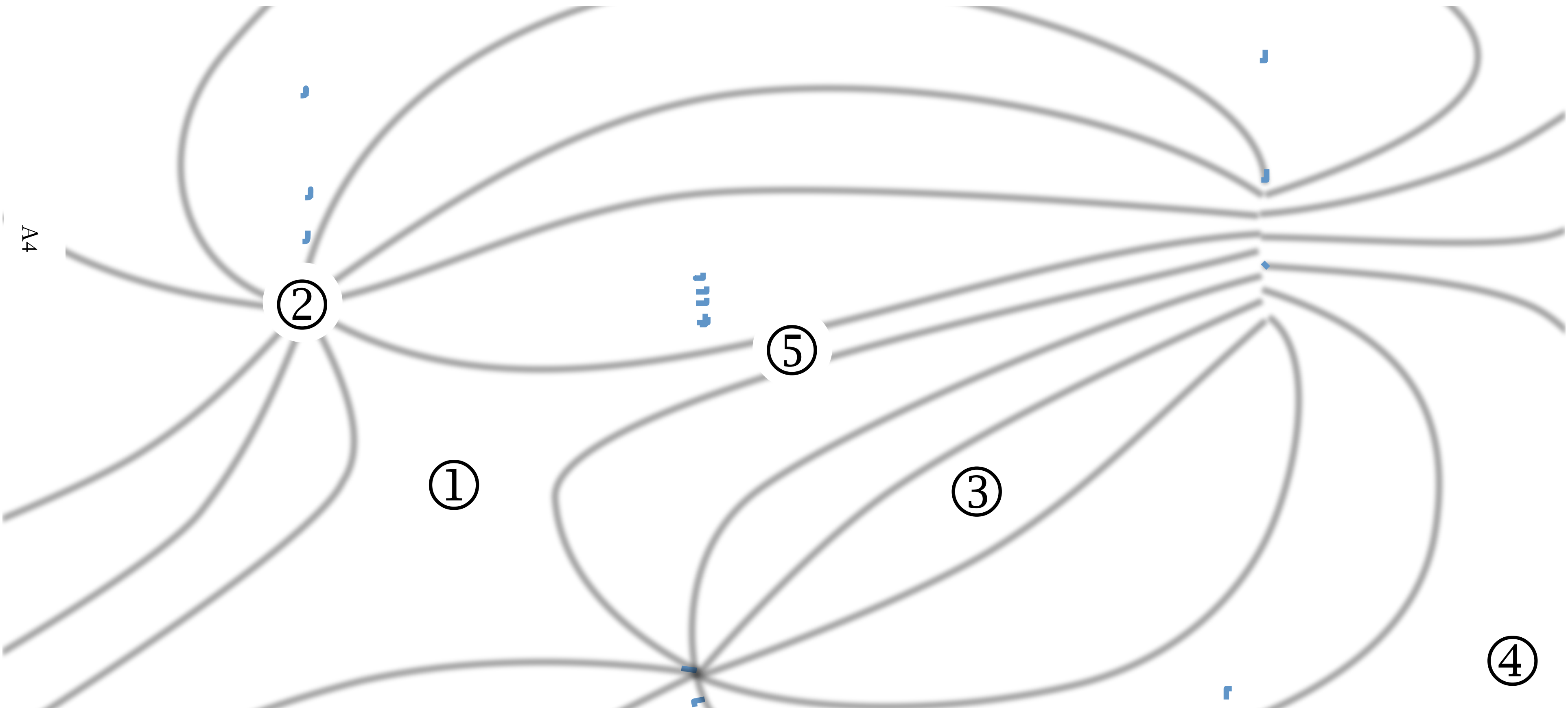
1. The electric field at P points to the left.
2. The electric field at P points to the right.
3. The electric potential at P is zero.
4. The electric potential at P is positive.
5. The electric potential at P is negative.
6. It is impossible to know the electric potential at P.

Shown below are the equipotential lines created by an unknown distribution of electric charge. If a test charge were placed at the points shown, at which location would it feel zero force? Choose all that apply.



⑥ Impossible to Tell

Shown below are the electric field lines created by an unknown distribution of electric charge. Which of the locations shown would have zero electric potential? Choose all that apply.



⑥ Impossible to Tell

Sparks can be created by putting a voltage difference across a pair of electrodes. By moving the electrodes one can find a certain distance at which the voltage required to create a spark is a minimum. If one moves the sparking electrodes farther away from each other *or closer to each other,* a spark becomes more difficult to create. You can see this on the graph below, which has voltage on the vertical axis and pressure times distance on the horizontal. Several different gasses are shown.

Given what you learned in the video about how electrical sparks are created, speculate as to why this minimum exists.