Key Stage 5 – Resistivity and error in measurement

Notes for teachers

At a glance

The digital age is built on an electrical component called a semiconductor. These are really important in electrical devices, as their electrical properties can be changed. Silicon is the most popular material for a semiconductor, hence the naming of “Silicon Valley” where most of the world’s prominent technology companies operate in, in California.

Researchers studying semiconductors are looking to create new semiconductors that could revolutionise our technology.

Learning Outcomes

1. Define resistivity and determine the equation of resistivity
2. Identify systematic and random errors
3. Assess the uncertainty of measurements

Each student will need

- Key Stage 5 – Resistivity and error in measurement activity sheet.
- Calculators.
- Prior knowledge: Students are expected to already have an understanding of Ohm’s law and what a semiconductor is.

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• OPTIONAL: Wire, digital multimeter, micrometer or Vernier caliper.

Possible Lesson Activities

1. Starter activity: Define resistivity and determine its equation
   
   • NOTE: This lesson has a large focus on literacy in physics and getting students to use their knowledge to try and interpret and define new words. Therefore this first activity is important to set the frame of mind for the remainder of the lesson.

   • Get students to predict what happens to resistance as:
     - The length of the wire increases.
     - The cross-section of the wire increases.

   • You can prompt the students by telling them to apply what they already know about resistance. For example, what happens to total resistance of components in parallel? And, what if those components were identical wires? Analogies can be made with cars passing through bottlenecks, or having more lanes on a motorway. Ultimately the students should be trying deduce that resistance is proportional to length of wire and inversely proportional to the cross-section of wire.

   • Show the students the equation of resistivity, defining it at as a property of a material, describing how much it resists the flow of electric current, measured in Ohm-metres. Ask students to:
     - Rearrange the equation to find resistance, and hence identify how resistance varies with length and cross-section, comparing to (and reflecting on) what they earlier predicted.

     \[ \rho = \frac{RA}{L} \]

     - Use the equation to fill in the missing values in the table on the activity sheet.
     - If time permits, get students to record some of the required measurements using appropriate instruments such as multimeters, micrometers or Vernier calipers.

   • To lead onto the main activity, ask students to think about how to link the equation for resistivity to semiconductors by considering:
     - “What effect will temperature have upon the equation?”
     - “What changes with temperature?”
     - “What measurements affects this value of resistivity?”
2. **Main activity:** Identify systematic and random errors

- To use the equation of resistivity in practice, a student will need to know relevant measurements, such as length and area, to a reasonable accuracy. When taking these measurements, they must be: *valid* and *repeatable*.
  - Ask students to define *valid* and *repeatable* by using examples. ["Measuring the voltage of the wrong component is an invalid, but repeatable measurement."]

- Explain to students the importance of considering errors in measurements using the example in the activity sheet.
  - Ask students to use the example measurements to calculate the *mean* and the *range*.

- **Introduce and watch the Oxford Sparks animation.**

- Using the topics discussed in the video, ask students to create a list of the errors in measurement that the research group may need to consider. (This task is allowing students to realise that errors in measurement occur *wherever* a measurement is taken. The list the students create does not need to be very specific and will be utilised in the next task.) [“Voltage, current, length, resistance, time, temperature, stiffness (force), energy.”]

- Explain to students the difference between *random error* and *systematic error*. Follow-up by asking students to determine when their examples of errors in measurement could be either a *random error* or *systematic error*.
  - **Systematic error** is when a measurement is consistently wrong due to the way in which the measurement is being done. For example, if equipment has not been calibrated, or there are imperfections in the object being measured such as the diameter of a wire.
  - **Random error** is when there is no clear pattern to the error. For example, measuring a moving object with a stationary ruler, where you have to use your judgment to where the object is. Interpreting readings can also lead to random error, such as when using a dial with unclear markings.

- **EXTENSION:** The *zero error* is when an instrument does not read zero when it should. Ask students to determine if the zero error is systematic or random. [Systematic if the reading is offset by a constant value].
3. **Plenary:** Assess the uncertainty of measurements

- One of the most important semiconductors is the transistor, which is vital to many electrical devices. The transistor is so vital it is even listed on the Institute of Electrical and Electronics Engineers list of milestones in electronics and was the reason of the awarding of the 1956 Nobel Prize in Physics.

- Creating smaller transistors is one of the stepping stones to creating more complicated and impressive electronics. To have such small transistors, physicists need to minimise uncertainties in measurements and have accurate and precise measurements.

- By building upon what students learnt earlier about the range of readings, cold call on students, asking the questions below. (This could also be done as group work as a think, pair, share exercise, depending on size of class.)
  - “What might an uncertainty in a measurement be?”
  - “How might a physicist work with uncertainties in their calculations?”

- Once students have predicted what it might be, formally define an uncertainty in measurement as the interval that we expect a true reading to be in. It is written after the measurement as a plus-or-minus value, which is either taken as:
  - Half the range (with appropriate rounding), if a range of values have been measured.
  - Specified by the instrument, if all measurements were the same. This is known as instrument precision.

- For example, a length might be written as 0.35mm ± 0.05mm. The uncertainty could be due to either a range in measured values, or the instrument precision.

- Once a measurement has been taken and the error has been considered, a physicist can describe a measurement by commenting on the:
  - **Accuracy** – how confident we are in a measurement. It is usually expressed with an uncertainty in measurement.
  - **Precision** – how exact a measurement is. It can fluctuate with random error, such as wobbling when using a ruler, where the precision is the range of values you read. When using digital readings, the precision is specified by the instrument.

- As a final task, consolidate learning of the lesson’s key concepts by getting each student to use the Frayer model on the activity sheet for each of the following:
  - **Resistivity**
  - **Uncertainty in measurement** (Challenge students to use the words: valid, repeatable, range, systematic, random, accurate and precise)

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Once students have completed the Frayer model for both, ask students to pair and share what they wrote, making any corrections as necessary.

MISCONCEPTIONS: Students may confuse accuracy and precision, however, a precise reading may not be accurate. For example, a reading may be exact, yet wrong due to systematic error (precise but inaccurate).

Web links

- Oxford Sparks animation on Semiconductors: http://www.oxfordsparks.ox.ac.uk/content/soluble-semiconductors-revolution-printing-21st-century
- The semiconductor research group at Oxford: https://www2.physics.ox.ac.uk/research/physics-and-application-of-soluble-semiconductors
- List of Institute of Electrical and Electronics Engineers Milestones: https://ethw.org/Milestones:List_of_IEEE_Milestones