Instructor Guide: Rules for Thermal Phenomena

This instructor guide gives detailed guidance for teaching the ACORN Physics heat and temperature tutorial. For more general guidance on facilitating ACORN Physics Tutorials, see our facilitator guide.

Overview & learning goals

ACORN Physics Tutorials are designed to support students in constructing their own models for physics concepts. This worksheet guides students to construct a **qualitative** model for thermal energy transfers and temperature changes among objects in contact with each other.

Students will practice:

- Constructing scientific explanations
- Generalizing their observations, prior knowledge, and explanations to construct a conceptual model
- Recognizing that they already have ideas relevant to physics understandings of heat and temperature

Students will be able to:

- Predict the direction of thermal energy transfer for objects in contact
- Define thermal equilibrium and predict the conditions under which it occurs
- Describe how mass, volume, and material influence thermal energy transfer.
- Distinguish thermal energy transfer from change in temperature.

Because this worksheet focuses on the process of constructing a model from one's own ideas, rather than a particular canonical model, we encourage instructors to guide students to test and refine their ideas as a scientist would, rather than to guide students toward a specific set of ideas. Students will construct a variety of models that are appropriate. For example, one student who completed this ACORN Physics tutorial constructed the following model:

> *Rule 1: Material matters: At room temperature, the block of iron has more energy than the block of brick, and the water has more energy than the olive oil.*
> *Rule 2: Thermal energy tries to balance itself: when an object is being cooled, energy flows out from the object, and when an object is heated, energy goes from the heat source into the object.*
> *Rule 3: The environment holds thermal energy as well: if an object is hotter than the environment, energy will flow from the object into the air, cooling the object down, and if the object is colder than the air, thermal energy will flow from the air into the object, heating it up.*
> *Rule 4: Once an object starts boiling (changing into gas), it cannot get to a higher temperature.*
> *Rule 5: Once the temperature stabilizes, objects in liquid share the same temperature as the liquid, even if they don't have the same amount of thermal energy.*
> *Rule 6: If you want to cool something (or heat up) faster, make an object with much less or much more thermal energy touch it (e.g. hot metal in cold water).*

Supplements to this worksheet:

This worksheet pairs well with PhET's Energy Forms and Changes simulation. We recommend using the "intro" version and turning on "energy symbols." Students can use this simulation to qualitatively test predictions about temperature and thermal energy changes in various scenarios involving water, olive oil, iron, and brick. While this simulation is useful, there are limitations to what it can be used to test (e.g., the simulation only allows one brick or iron cube, and the masses cannot be changed).

What is this ACORN Physics Tutorial designed to do?

This worksheet asks students to explain several simple experiments involving heat transfers between different objects. These scenarios were selected to highlight that an objects' mass, temperature, and the material it is made of affect how much heat (thermal energy) is transferred to or from it.

I. Objects of the same material

This section uses **explain-style questions** to elicit students' ideas about heat transfer between different objects. Our expectation, in choosing these scenarios, is that students already have many relevant ideas–ideas that we typically include as learning goals in introductory units on thermal phenomena–that they will bring to bear when asked to explain the observations in this section. Our goal is to support students in getting those ideas down on paper.

Students first consider an experiment in which identical blocks are placed in thermal contact in an insulated box (i.e., no energy is transferred to the environment). Then, they consider a similar scenario with two blocks of different sizes that are placed into identical beakers of water(again, we assume no energy is transferred to or from the environment). After students explain their ideas about each experiment, they are asked to draw an energy diagram to illustrate their thinking. We've noticed that students often spontaneously sense-make as they represent the relevant energy transfers and transformations, and we encourage students and instructors to spend time discussing the details of these qualitative representations[1].

Fruitful ideas (e.g., conceptual resources) that students commonly use to make sense of either or both of these scenarios include (Abraham et al. 2021):

- **Heat transfer is directional (from hot to cold).** For example, when students are discussing question I.A they might say something like, "The two blocks end up the same temperature because the transfer of energy goes from high to low," or "the energy from the hot block transfers to the cold block."
- **An object's physical properties (mass and material) matter for thermal phenomena.** For example, when students are discussing question I.B they might say, "Greater mass requires more energy to be the same temperature," or, "Iron retains energy better, so the brick cooled down faster while the iron stayed hot."
- **Hotter objects have more energy.** A student might reason, "So we put heat (energy) in and the temperature will go up."
- **Energy is conserved.** Students may refer to energy transfers and transformations in their explanations of various thermal phenomena, or they may use the amount of energy initially in a system as a constraint that affects what can happen in the system.

Instructors are encouraged to listen for and highlight ideas like these in students' conversations, and to ask open-ended questions to understand students' thinking more clearly. Instructors should encourage students to write down their relevant ideas in the "model-building box" on the first page of the worksheet. It is not important that students' ideas are completely correct or fully fleshed out at this stage of the worksheet, because they will extend and revise their thinking in the following section. However, it is

[1] This worksheet asks students to construct Energy Tracking Diagrams for several scenarios. If your course does not use Energy Tracking Diagrams, students may draw graphs, bar charts, or other energy representations they are familiar with.

essential that students recognize what heat, temperature, and energy ideas they *are using* so that they can build from them in the rest of the worksheet.

II. Objects of different materials

This section focuses on an **explain-style question** about an experiment in which a hot cube of iron is placed in a room-temperature beaker of olive oil. Assuming no energy is transferred to or from the environment, the iron and oil come to an equilibrium temperature of 35°C (you can verify this using $Q = mc\Delta T$). This scenario is designed to support students to further articulate and refine the resources elicited in part I. In particular, in part I, students are asked to think about a scenario in which two cubes, one hotter than the other, are placed in two separate beakers of water. This scenario often elicits thinking about fixed amounts of energy raising or lowering the temperature of two different objects (water and blocks). This new scenario likewise asks students to consider how much energy it takes to raise or lower the temperature of different materials particularly by 1°C, building from the previous question, and invites students to develop more quantitative ways to express their existing models. Instructors can choose to extend this section by asking students to predict or explain similar experiments (Owen 2024)– for example, what if the iron was twice as massive, or was placed in a beaker of water instead?

III. Reviewing your Rules

Here, students revisit, connect, and refine the set of ideas used throughout the worksheet, in conversation with their peers. This is a challenging task, and instructors may participate in the refinement of students' models by highlighting important ideas and connections, asking questions to probe particular ideas that are unclear, or suggesting thought experiments to test students' developing models. It is important that students develop models from their own ideas (rather than instructors' suggestions), but instructors can encourage students to add to or refine their model if it does not accurately predict or explain the behavior of an experiment they consider. The example model at the top of this guide illustrates that students can develop a qualitative conceptual model that accurately explains a variety of heat transfer experiments on the basis of their work together in this ACORN Physics Tutorial. The example model also includes a rule about temperature change as a fluid boils, which is not explicitly addressed in the worksheet. This illustrates that the worksheet allows space for students to pursue their own questions and examine more experiments than the ones given on the worksheet (e.g., by testing ideas in a simulation).

What are specific strategies to help students with this worksheet?

- Keep track of questions that students express and suggest ways they can test their questions using equipment or simulations.
- Help students to identify and resolve inconsistencies in their ideas and models.
- Suggest thought experiments to clarify what a student is thinking or to resolve inconsistencies in their ideas.

What research has been done to develop and/or test this worksheet?

Learn more about the research involved in this worksheet here:
https://www.physport.org/curricula/ACORN/research#heatandtemperature