# B5 We build a thermal solar plant – With a magnifying glass and mirror

The two subexperiments on concentrating sunlight with a lens and a mirror are particularly suitable in physics class for the students to become acquainted with some laws of ray optics and thermodynamics based on a highly topical subject or to verify material already learned. But the experiments can also be used for a project day on renewable energy or energy transition. The materials and apparatus supplied are sufficient to allow four groups of students to work simultaneously.

## 1 Main question

How can we use the vast amounts of energy from the sun, which radiates more energy to the Earth every day than the entire world can use in a year? What possibilities do we have for tapping into this source of renewable energy? The students will learn about approaches to doing so in simple, hands-on experiments. It's a huge leap "from the burning lens to the solar power plant". In the group experiments, though, the students will come to know firsthand the basic principle and the difficulties with the technical implementation of renewable power generation.

## 2 Integrating the experiment into the teaching context

### 2.1 Basic principles

It is preferable, but not absolutely necessary, for students to have prior knowledge of the following:

- From the field of optics:
  Light as electromagnetic radiation (→ spectrum)
  Optical lenses and mirrors as instruments for changing the direction of rays
  Convergent light beam for forming focal points
- From the field of thermodynamics:
  Thermal radiation as the transport of energy without matter (radiant energy)
  Temperature measurement with an electric resistance thermometer

### 2.2 Relevance to the curriculum

In physics classes for students aged 12 to 14 years, the following subjects are discussed when the basic principles of optics are taught: Parallel, convergent light beams; light ray as an ideal narrow, parallel light beam, optical spherical lenses (convex lens as a converging lens → focal point), beam paths with a concave reflector. In thermodynamics, there are areas of overlap with the topics of temperature measurement, heating of a body through the absorption of radiant energy; specific heat capacities; energy transport without the presence of matter (→ thermal radiation); the sun as a thermal radiator, and the solar constant.

**Topics and terms:** beam path, burning lens, concave, concave reflector, converging lens, convex, electromagnetic radiation, energy density, focal point, light beam, light rays, magnifying glass, optics, parabolic reflector, power generation, renewable energy, solar power plant, spherical lens, sunlight, thermal radiator, thermodynamics, thermometer

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## 2.3 Skills

The students will ...

- know about the concentration of light rays from a flashlight to bring the rays from a divergent to a nearly parallel form.
- Learn from their own practical experience with a watch glass or magnifying glass that they can capture sunlight and change its direction.
- experience the fact that focusing sunlight using optical instruments will significantly increase the energy density such that they can even quickly ignite paper. This will be convincingly demonstrated to the students in simple experiments and especially using simple tools.
- come up directly with ideas for how to make this type of "power generation" useable, by discussing and analyzing the results of the experiment.
- recognize the importance of a sustainable energy supply for the future (→ thermal solar plant; e.g., DESERTEC project) and make it one of their own concerns.
- develop a conscious, responsible way of dealing with nature and resources.

## 2.4 Explaining the experiment in the teaching context

### 2.4.1 Subexperiment 1: Setting fire to a strip of paper using a magnifying glass as a burning lens

The point of this subexperiment is to generate higher temperatures using a magnifying glass as the burning lens. The students' task is to find out hands-on how the burning lens, as a biconvex converging lens, must be positioned (object side) in the sun's beam path (parallel light) and what distance they must select on the image side so that the energy is intensified as much as possible in the focal point. The attainable energy density itself depends mainly on the radiated area of the effective lens surface.

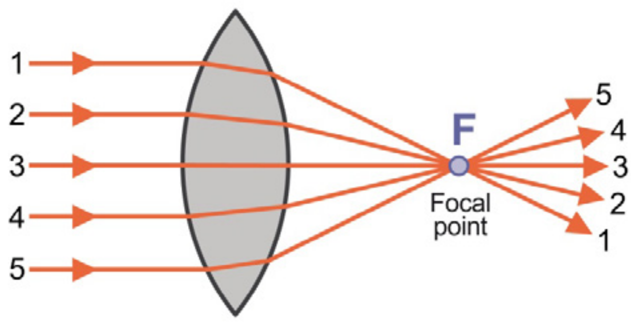


Fig. 1: The focal point of a converging lens. The light is coming from a great distance and is thus parallel. The lens collects ("converges") it into a point.

For a lens with an area of 250 mm$^2$, the radiant energy is focused to approx. one-hundredth of the area (approx. 2.5 mm$^2$). Decreasing the size of the focal spot even further has a tremendous effect on the temperature. Bear in mind that the maximum temperature can be reached only by securing the thermometer or paper at the focal plane. Since the sun moves, it is necessary to reposition the burning lens, but this isn't a big problem in the brief duration of subexperiment 1. The students will very quickly observe the development of a wisp of smoke and the strip of paper bursting into flames.

When a solid substance like paper is ignited, flammable gases develop through the degradation of the cellulose. The temperature of 233°C (451°F) required to ignite dry paper can be achieved with the burning lens; dark paper catches fire far more easily due to the increased absorption effect.

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### 2.4.2 Subexperiment 2: We heat water with the sun

In this subexperiment, a small amount of water will be heated by focusing the sunlight. In principle, this is similar to the construction of a “solar cooker”, which is built with a parabolic reflector and is used in southern countries that have experienced little industrialization. The focal point for the burning mirror used is approx. 3.5 cm above the bottom of the reflector for radiation at a perpendicular angle. An optimum heating effect is however ensured only if the sunlight shines in perpendicularly, which makes it necessary to tilt the mirror to a greater or lesser extent depending on your latitude. Because the students must constantly look inside the mirror to determine the focal point, it is mandatory that they wear sunglasses offering a high level of protection.
Otherwise, the ray optics of the burning mirror are comparable to that of a convex lens, only that the focal point is on the side facing the sun.

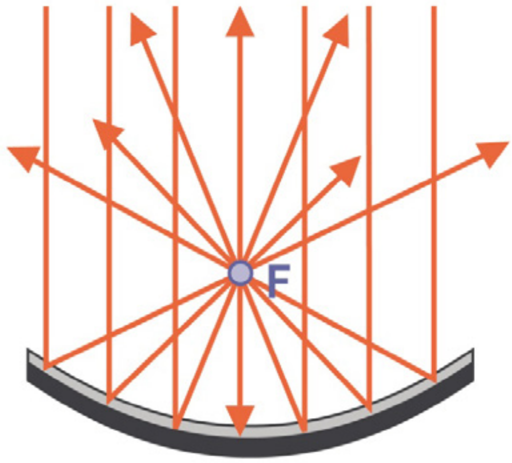

Fig. 2: Focal point of a concave reflector. The light is coming from a great distance and is thus parallel. The lens collects (“converges”) it into a point.

The glass containing water (with a high specific heat capacity) will be heated in this subexperiment. Due to the extended time frame of the experiment, it will be necessary to reposition the reflector and the test tube depending on the altitude of the sun. It requires some skill to keep the “radiated focus” constantly fixed on the heating point. (This technical problem is solved in solar power plants through electronically motor-controlled repositioning of the reflector.)
Just like with the magnifying glass as the burning lens, an increase in the size of a parabolic reflector multiplies the energy density. Temperatures of up to 400°C are possible, whereby a total current output of greater than 50 MW per power plant block can be generated. This is demonstrated by modern solar thermal power plants, e.g., in southern Spain (Andasol), Morocco, and California.

## 2.5 Experimental variations

- The students can work in pairs for subexperiment 1. Subexperiment 2 is somewhat more complex, and the students should work in teams of four, with two students setting up and conducting the experiment and the other two measuring and analyzing the values.
- If subexperiment 2 is to be conducted outdoors, the test tube must be shielded from any wind; the wind’s cooling effect should not be underestimated. Late morning is the preferred time, because the sun is higher.
- However, the two subexperiments can also be conducted simultaneously in two groups. Then the next time the class meets, the individual teams can share their expert knowledge from the subexperiments with the other group.
- All subexperiments can be conducted with each of the age groups mentioned. Teachers can differentiate the lesson by varying the depth of the analysis and follow-up questions.

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# 3 Additional information on the experiment

You will find additional media for preparing or for further study of this experiment on the Siemens Stiftung Media Portal:
https://medienportal.siemens-stiftung.org

Another media package specifically on the topic of "Solar thermal energy and photovoltaics – energy forms with a future" is available on the Media Portal.

**Optional: Additional experimentation options**

- During the introduction, you can use a spoon to demonstrate the operating principles of convex and concave lenses.
- The students can recognize and describe their own reflection on the inside and outside of the spoon: (convex: reduced in size, upright/concave: reduced in size, inverted)

# 4 Notes on conducting the subexperiments

## 4.1 Facilities

The experiments can be conducted only on sunny days in direct, intense sunlight. It is best to do so outdoors or at an open window. The air should be calm and the air temperature should be at least 20°C. In principle, the winter sun should also be sufficient. However, solar radiation is greatly weakened through a closed window, and outdoors too much heat is lost to the cold air. Bright photo/video lamps with a parallel light beam and output of approx. 500 watts and higher work just as well. Low-priced lamps with high-performance halogen light bulbs (e.g., from a home improvement store) would have to be tested, because the light may not be sufficiently parallel.

## 4.2 Time required

| | Preparation | Execution | Analysis | Discussion |
|---|---|---|---|---|
| Subexperiment 1 | 5 min. | 10 min. | 10 min. | 10 min. |
| Subexperiment 2 | 10 min. | 30 min. | 10 min. | 5 min. |

## 4.3 Safety aspects

The students may conduct the experiments only in the presence and under the supervision of the teacher.
The teacher is to point out to the students that the provided materials may be used only according to the respective instructions.
For these experiments, watch out for the following potential dangers and make your students aware of them:

- Use the focal point of the magnifying glass in sunlight in a controlled manner. Do not aim the focal point at anyone's eye!
- Due to the risk of blinding from the magnifying glass and burning mirror, it is imperative that at least the student who focuses the mirror wear sunglasses and be supervised by the teacher.
- Do not look into the burning mirror while heating the water.
- Working with a flame can result in burns or fires. Before a lighter is used for the first time, the teacher must check that it is working properly and, above all, adjust the flame height.
- Make sure that no damage can occur to water-sensitive materials and apparatus.
- Have water at hand to extinguish the burning paper.

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## 4.4 Apparatus and materials

**Required materials that are not supplied:**

- Preferred: tripod with clamp.
  Alternatively, books or a stable drinking glass or preserving jar can be used as a substitute for the tripod.
- Water
- White paper
- The students must bring sunglasses.
- One lighter per student group (if possible, a gas igniter) or matches

**Supplied:**

The apparatus and materials supplied are sufficient to allow **four** groups of students to conduct the experiments simultaneously.
Safety-relevant materials and apparatus must be tested for proper functioning before being handed out to the students.
The following materials included in the kit are needed for **one** group of students:

| Material | Quantity |
|---|---|
| Digital thermometer* | 1x |
| Magnifying glass as burning lens | 1x |
| Mirror, concave (as burning mirror) | 1x |
| Paper, black, DIN A4 | 1x |
| Tape | 1x for entire class |
| Tea light | 1x |
| Teaspoon | 1x |
| Test tube clamp | 1x |
| Test tube, glass, 13 cm | 1x |

*Remove the plastic sleeve before the first use. Press the “on/off” button to turn on the thermometer. After completing the experiment, turn off the thermometer again (press “on/off” again). Press the “°C/°F” button to switch between the Celsius and Fahrenheit temperature scales.

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Fig. 3: Apparatus and materials supplied for one group of students.

## 4.5 Cleanup, disposal, and recycling

All apparatus and nearly all materials from the kit can be reused. Therefore, after the students have completed the respective experiment, they should put the apparatus and materials back in the appropriate boxes and return them to the kit. This practice will ensure that you and your colleagues will find everything again quickly the next time the kit is used.
Apparatus that become dirty during the experiment, such as cups, bowls, spoons, and test tubes, should be cleaned before being returned to the kit. We recommend that you have the students do this immediately after they have completed the experiment.
Also make sure that the apparatus are in working order for the next time. For example, recharge used accumulators immediately (It makes sense to charge the accumulators even if they will not be used for an extended period.).
Materials that cannot be reused, such as used pH test strips and filter paper, should be disposed of properly.
The waste that accumulates during this experiment can be disposed of in the regular trash or poured down the sink.

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