2. Laser into the darkness

An experiment showing how a laser beam bounces off dust particles. It aims to explain the principle of operation of the laser dust sensor.

Keywords: light scattering, dust sources, dust detection, measuring instruments

Materials from the box

1. black sheet of paper
2. laser pointer
3. Incense

Materials outside the box

1. a roll of black yarn or fabric
2. glue stick or adhesive tape
3. scissors
4. Antiperspirant spray
5. cosmetic powder or powder
6. gas igniter

Safety

1. We do not shine a laser in the eyes.
2. We don't look into a beam of laser light.
3. We do not use open flame when pouring powder.

Research questions and experiments

Preparation of the laser beam observation device

1. **How does a laser light beam behave in the presence of air pollutants?**

1. We roll a sheet of black technical paper into a tube with a diameter of 5–6 cm and glue it along the long side.
2. In the central part of the tube, cut a rectangular hole lengthwise with dimensions of approx. 2 cm
3. Plug one end of the tube with a roll of black yarn or black soft fabric and seal it tightly with adhesive tape.
4. The other end of the tube is also plugged with a roll of yarn or fabric, but in such a way as to be able to place the laser pointer tip inside it (leave the pointer button outside), and then seal the outlet tightly with adhesive tape.

Control sample

Avoiding intense external lighting, we turn on the laser pointer and observe the inside of the tube through the window.

Experimental trial

At a distance of about 0.5 m from the tube, spray an antiperspirant (this should last no more than 1 second). We turn on the laser pointer and observe the inside of the tube through the window.

Questions about observations

What was visible inside the tube in the first attempt, and what in the second?

What did the laser light beam look like before and after the antiperspirant spray?

1. **Does the size of the particulate matter affect the behaviour of the observed light beam?**
   The course of the experiment

In the area of the tube, we spray powder (the largest particles) and observe the way the laser light beam streaks move.

We wait 5 minutes, then spray an antiperspirant (medium-sized particles) around the tube and observe how the laser light beam streaks move.

We wait 5 minutes, after which we light the incense stick (the smallest particles) and observe how the laser light beam streaks move.

Questions about observations

How did the laser light beam differ in appearance when antiperspirant, powder and incense smoke were sprayed?

Expected result

In contact with each of the tested substances, the laser light beam will behave slightly differently. Since powder, antiperspirant and incense smoke differ in particle size, we will observe differences in the size of the flashes. For the largest particles (powder) flashes will be clear and point, in the case of smaller particles (antiperspirant) – smaller and more numerous, forming something like a beam, and for the smallest particles (incense smoke) – small enough to be visible in the form of a delicate streak.

What can go wrong and how to deal with it?

After spraying the substance, the laser light beam is poorly visible inside the tube.

To avoid such a situation, it is recommended to conduct the experiment in a slightly darkened room.

Observation of the laser light beam inside the tube is disturbed by the incoming light from the outside.

In order to avoid lateral reflections on the inner surface of the tube, the presence of which may distort the measurement results, the inside of the tube must be completely blackened. To do this, tightly cover any gaps through which light may penetrate.

Explanation of the observed phenomenon

Most of the popular measuring instruments available on the market for the detection or avoidance of suspended dust (PM2.5 and PM10) are based on the use of the phenomenon of scattering the light beam on solid particles. When we drive a car with the headlights on through the fog, we see a beam of light in front of us. However, what we perceive then is not the light emitted directly by the headlights, but the light reflected in the thousands and millions of water droplets that form the fog. The light of the headlights switched on during the day in fogless weather is not visible, because there are no particles in the air on which it could scatter. Dust meters work in the same way: a light beam (infrared radiation or laser light) illuminates a "sample" of air containing dusts in an appropriate way, and a separate optical system examines the reflected light. The intensity of the reflected light is proportional to the amount of particulate pollution.

Most low-cost sensors measuring PM10 give the total mass or number of all particles in the size range, e.g. 0.3–10 micrometres (μm). More complex versions of such instruments use many different beams incident at different angles and additional separation filters to "separate" the signal reflected from impurities of different sizes, making measurements much more precise.

TEACHER'S CARD – LASER INTO THE DARKNESS

Air suction fan

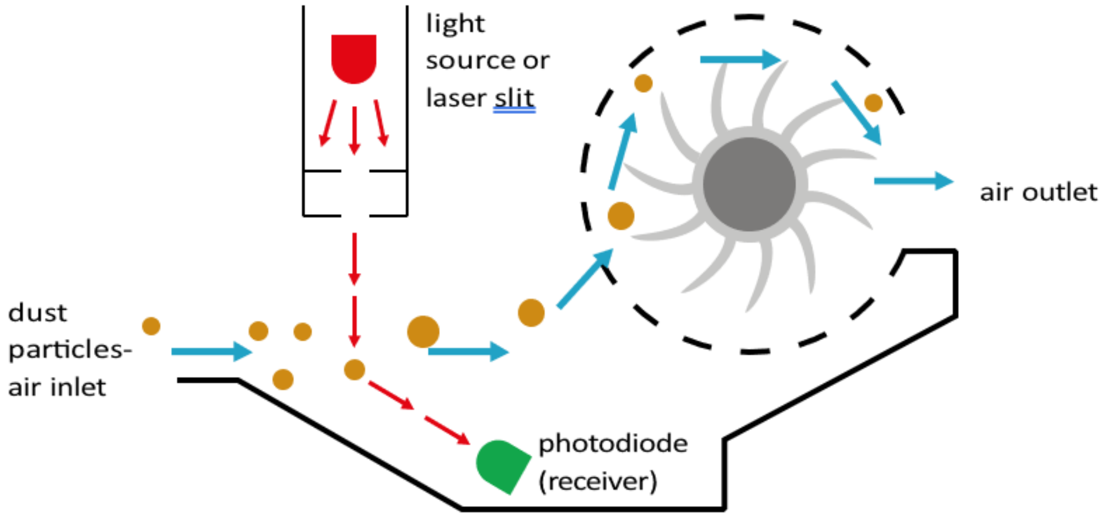

Fig. 1. Diagram of the construction of the dust sensor

The device built by us in a simplified way illustrates the principle of operation of such devices and simulates their operation. A laser light beam in clean air is practically blind. It is only visible by the sprayed mist from the antiperspirant. The trace of fog is visible as a thin line. In this smudge, places of thickened and rarefied dust can be observed in the form of darker and lighter zones moving depending on the movement of the air mass. In contrast, the speed of trace disappearance depends on the ventilation conditions in the environment. Most of the mist from antiperspirant is condensed alcohol, which evaporates quickly; on the surface of the tube can settle, leaving streaks, other substances, e.g. aluminium salts.

In the case of using dust with relatively large particles (powder) in the experiment, on the line of incidence of the laser beam we observe clearly visible, point "flashes", indicating that the laser light encounters larger impurities. This type of dust falls faster, and thus – the visibility of the beam decreases faster.

Observed phenomenon and air pollution

Particulate matter is a heterogeneous substance – its particles have very different sizes, shapes and chemical compositions. The latter is incomparably more complicated than the composition of other smog components. Simple measuring devices (similar to the one used in our experiment) do not recognize the shape, size, weight or color of the contaminants. Due to the principle of measurement, the amount of light reflected from the dust is measured) they only receive information about the duration, often the fussiness and intensity of the pulse. Then, on their basis – based on algorithms developed in the course of more thorough research – they give the PM value in micrograms per cubic meter (μg/ m, so this is an indirect result, because when making a measurement, we do not actually weigh dust.

The results of air quality measurements carried out as part of the State Environmental Monitoring are reference. Official stations included in the PMŚ use two-stage measurements: in the first phase, measuring devices make automatic measurements, the results of which – although less accurate – are provided practically on an ongoing basis (and after verification provided with a slight delay on the website of the Chief Inspectorate for Environmental Protection – GIOŚ); in the second phase, however, after a certain time, filters are removed from them and subjected to gravimetric measurements (i.e. they are weighed) and on this basis the concentrations of dust and benzo(a)pyrene (BaP) are determined very precisely. After this second measurement, the results are verified on the GIOŚ website.

More information on air quality monitoring and methods of measuring the concentration of particulate matter can be found in chapter eight of the monograph "Fine dust in the atmosphere".