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solution to the problem no. 15
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Luminescent sugar

Investigate and explain the light produced when sugar crystals are pulverized. Are there other substances with the same property?

Abstract

Already FRANCIS BACON discovered the light produced by sugar in 1605.
In my report I tried to explain this light and to show that there are even uses for it.
I also describe experimental results, but experiments are on the one hand very difficult if you want to quantitative results and on the other hand difficult to show, because the light is very weak.

Thanks

I like to thank Franziska Hausmann for preparing our reports together and
StR Herbert Brandl for his support with the experiments, the substances he gave us and his good idea for the coffee grinder.

Overview

1 Introduction

By pulverizising sugar crystals you observe light effects. The produced light should be investigated and other substances with the same property should be found.
After a time of 10 – 15 minutes for the adaptation of your eyes in the dark you can recognize the light. Sugar is smashed manually with a hammer or pulverized with a mortar or you rub cub sugars to each other. You also can produce the light by a shock of temperature.
The intensity of the light can be estimated visually because a rod cell in your eye is already stimulated by only one few photons.
The duration of the light is about 10 milliseconds in the maximum, normally as long as the destroying force takes effects, at some substances there is a longer light.

2 Definitions

Luminescence is the emission of light – visible and not visible in the UV-sector – of gaseous, liquid or solid substances, that isn't based on its temperature. So this light is also called "cold light". Different substances have lights of different colours (UV till darkred), sugar (saccharose) is blue (green). There are different phenomena of luminescence, e.g.

- Photoluminescence: The light is caused by absorption of light.
- Chemoluminescence: The energy for the light comes from a chemical process.
- ...
- Triboluminescence: The energy for the light comes from a mechanic process. e.g. rubbing, pressing, crushing, temperature chock (sugar in liquid air).

In our case it concerns the triboluminescence. *"Tribein"* is Greek and means "to rub".
Substances that are able to triboluminescence are divided in substances with and without photoluminescence. Photoluminescence is the emission of light after stimulation with UV-light, the emitted light consists of longer wavelength Sugar is a substance without photoluminescence, so we don't have to care about this. The ones with photoluminescence can have a longer light.

3 Experiments

Pure sugar:

There's a blue or green light if you use glucose, maltose, rhamnose or saccharose,
there's no light if you use fructose, fucose, galactose, mannose or cellubiose.

Sweets:

Experiments with sweets, which contain also other substances:
E.g. the aroma-substance methylsalicylat supports the light intensity and changes the colour (wavelength) → you can see it better.

Other substances:

with light:

salt, quarz, water spavin, apatit, sylvin, plaster, filed spavin, carnallit, morble, ...

without a light:

sulphur, baryt, epsomit, ice, coal, apaphyllit, ...

Piezoelectric crystals:

(piezoelectric means the substance is charged under pressure)
Piezoelectric crystals like sacchrose have triboluminescence.

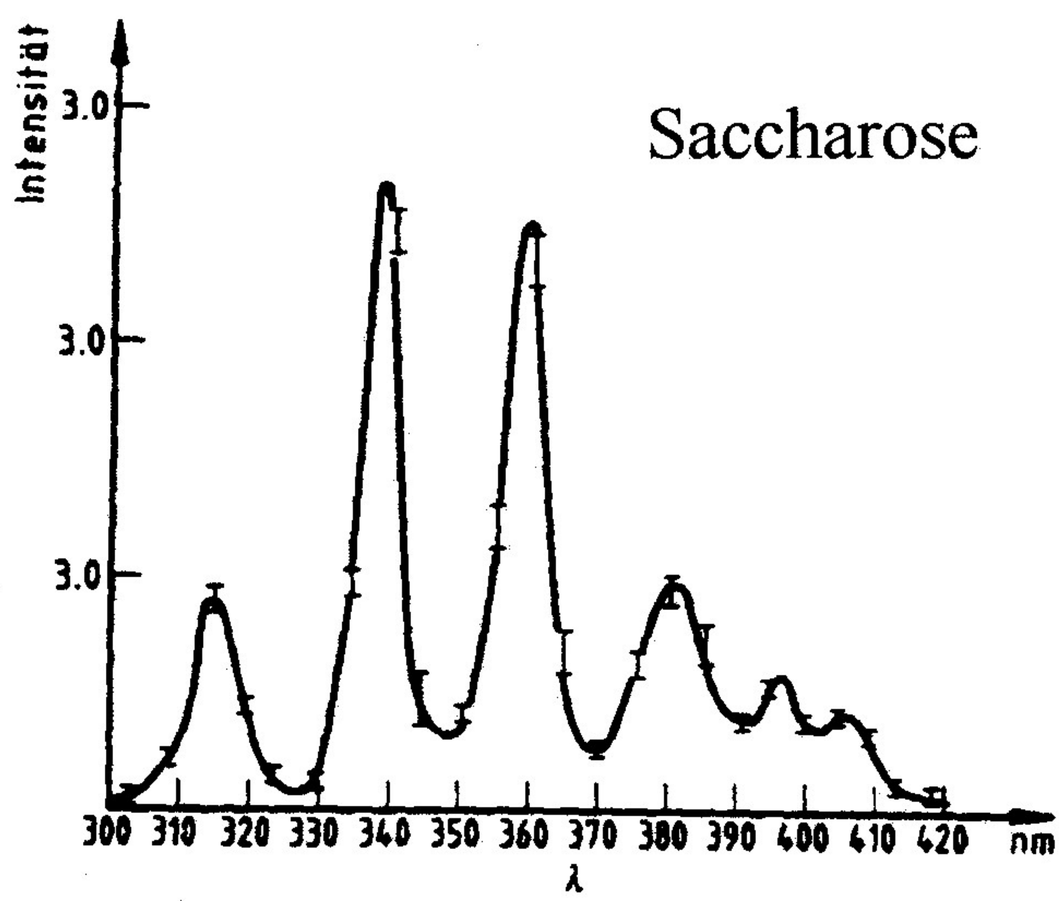
Notes

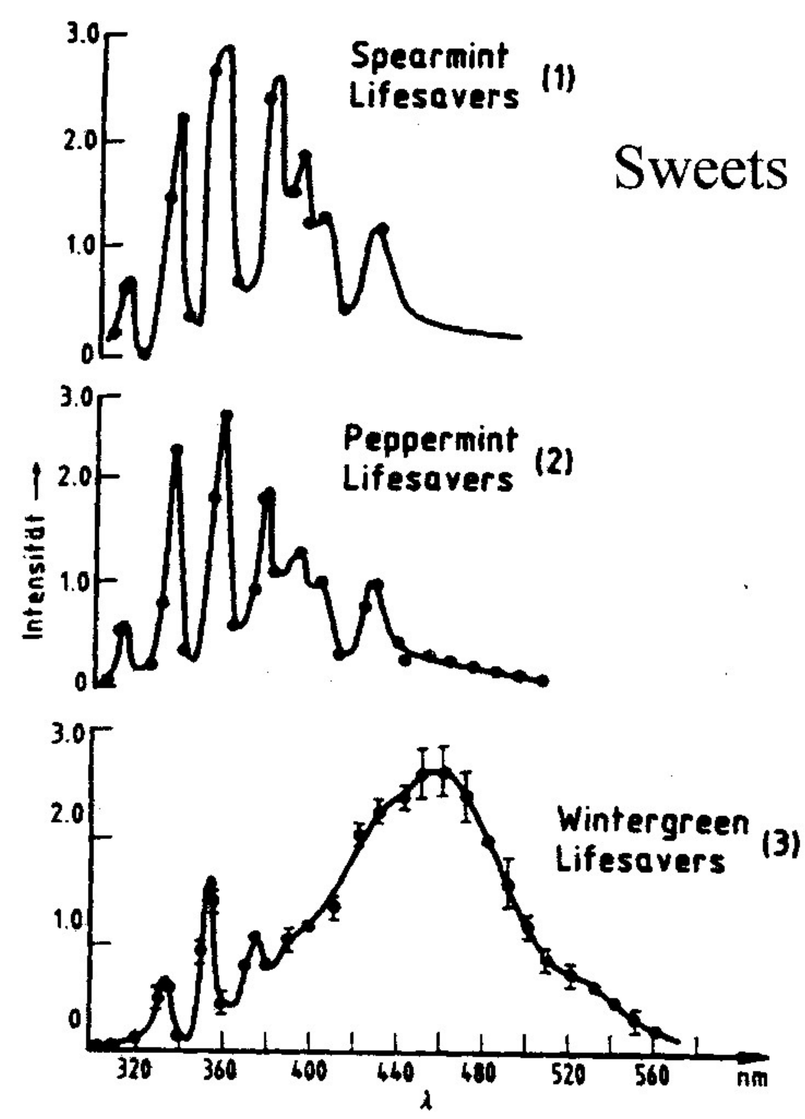
- Only crystalline and electrically not conducting substances have a triboluminescence.
- The bigger the area of the breaking is – the longer and more intensive is the light.
  The intensity is proportional to the breaking area (depending on the specific breaking velocity of the crystal, it's measured by gas adsorption method).
- Pollution in the crystal that cause defects of the crystals can increase ore weaken the triboluminescence.
- The intensity depends on the structure of the crystal and the position of the breaking area.
- There is only emission if the crystals are big enough. We could see this in our experiments with cub sugar in a coffee grinder, there was the light only some time, then the sugar was too small.

4 Spectrums

The triboluminescence spectrums are similar to the emission-spectrums of the gas around the sugar. So we recognize that the triboluminescence depends on the surrounding gases in high grade. Experiments in argon or helium show this: The light is more intensive and longer than in air. Also in the vacuum there is a light. (intensity $\sim$ pressure)
The spectrum is most of all similar to the emission spectrum of N_2. It seems that the N_2 is responsible for the emission of the light. In the vacuum still rest some N_2 molecules, that are adsorbed on the sugar surface, light can be emitted. If you make experiments in neon you regard a red light that is typical for stimulated neon-atoms.
At sugar it concerns so a light of discharching of a gas and no light of a solid, because the emission spectrum is the one of N_2. At phosphor for example there is a light of a solid.

Spectrums:

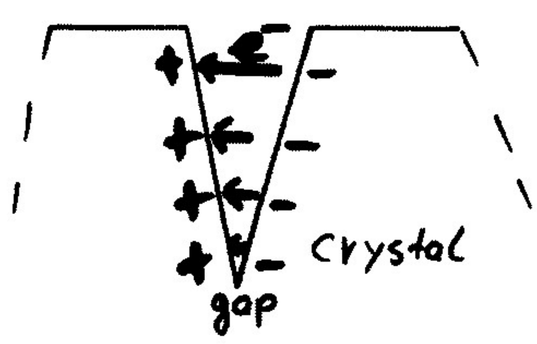


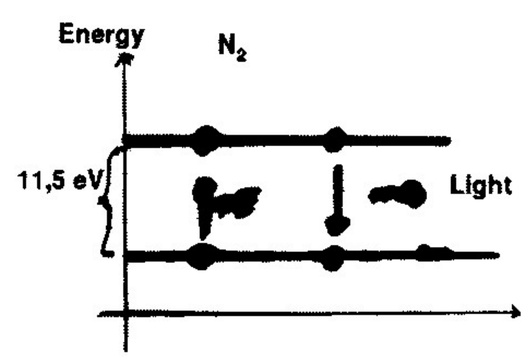


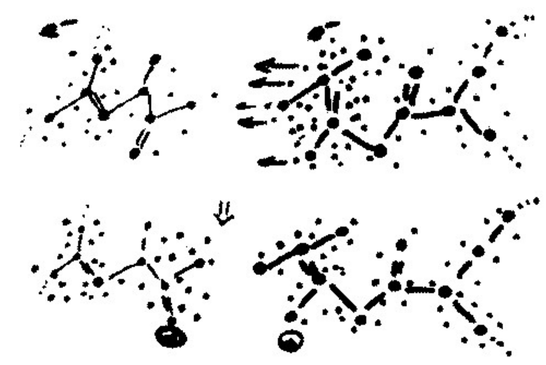
In the spectrum there are clear peaks at about 330 nm: these are the peaks of the emission of molecular N_2, (it's the 3 Π_u to 3 Π_g crossing.) These peaks are visible at all kinds of sugar.
Normally the light is weak because the main part of the light is in the non-visible part of the spectrum in the UV.
The mentioned aromas in the sweets absorb this light, are stimulated and emit a light with less energy (blue-green 400 – 500 nm) that you can see. The intensity of the light is higher.
The quantitative experiments are very difficult, because the intensity isn't high, you need very sensitive machines. So we took this diagrams from literature and from another group of youth that had the possibility to make the large-scale experiments, that needed a lot of time, in an university. They used there photomulitpliers and saving oscilloscopes.

5 Mechanism

The mechanism of the triboluminescence.:







- Breaking a triboluminescent crystal areas of breaking develop. Charge that was tied is freed from the surface.
- Charge can accumulate if the material is piezoelectric and not electrical conducting, if there are many electrophil and nucleophil parts in the molecules or if there are defects in the crystal sufficient to permit significant charge separation.
  This separation of the charge is the same as if you are separating two plastic films or in rubbing experiments.
  The Electrons are not symmetrical in the big molecules, best if there are polar axis, are freed.
- When the voltage is great enough, electrons escape from the surface (exoelektron emission).
- Air comes into the gap, N_2 is absorbed. A cathode-ray begins. The crashing electrons stimulate the N_2. The N_2 emits light.
- The electrical fields must be high enough that light can be produced. 11.5 eV is needed to excite the dinitrogen bands observed from sucrose and other nonphotoluminescent crystals.
- The UV-vis emission of the gas (lightening) excites in some crystals (crystals with photoluminescence) the molecules of the crystal (240 – 450 nm).

The electrical field can stimulate only the crystal or the gas, at substances without photoluminescence like sugar, only the gas – N_2 – can be stimulated and be responsible for the light.
Light is only emitted, if the structure of the crystal is suited (electron distribution or defects) for a high enough electrical field. So only some sugars have a triboluminescence.

6 Some calculations about the gaps

gap-width

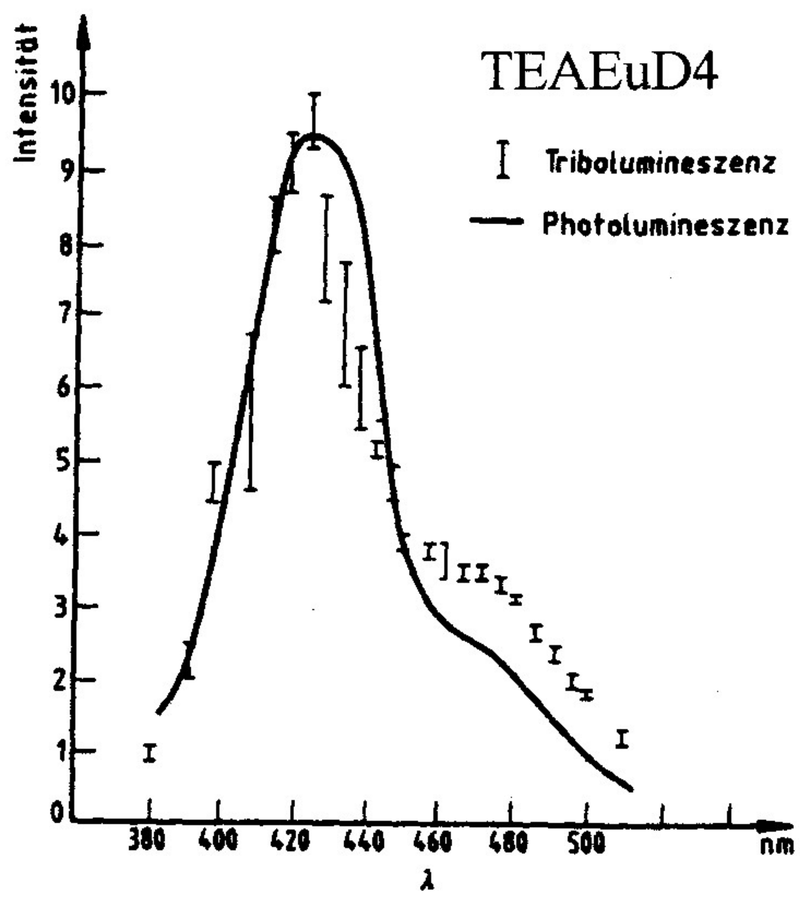
$$U = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{r}$$

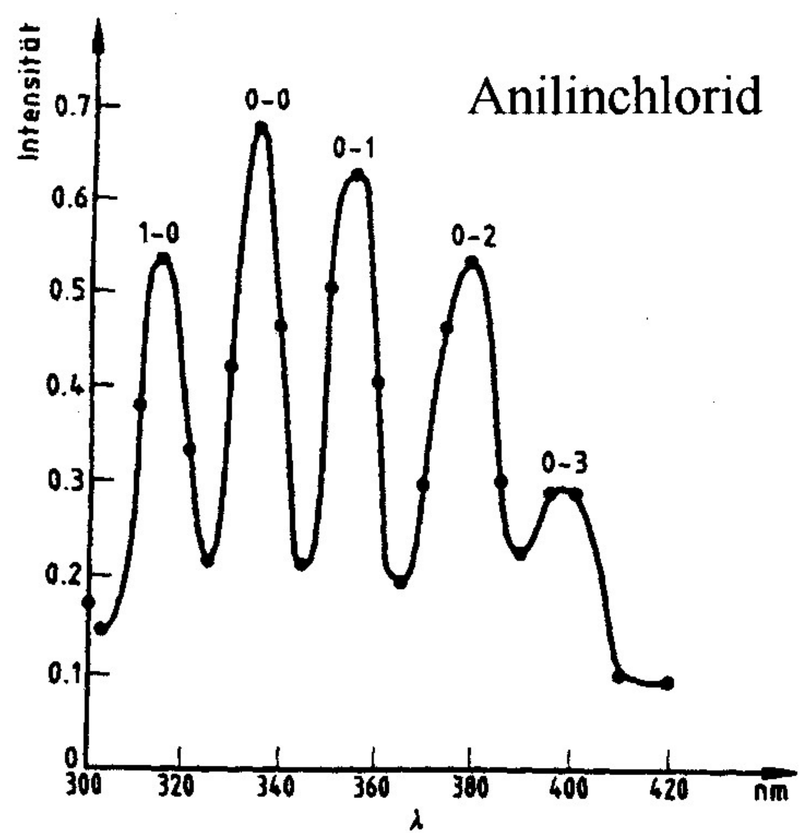
for sugar you get with $U_0 = 11\,\mathrm{V}$, $r_0 = 1,3 \cdot 10^{-7}\,\mathrm{mm}$.

gap-depth

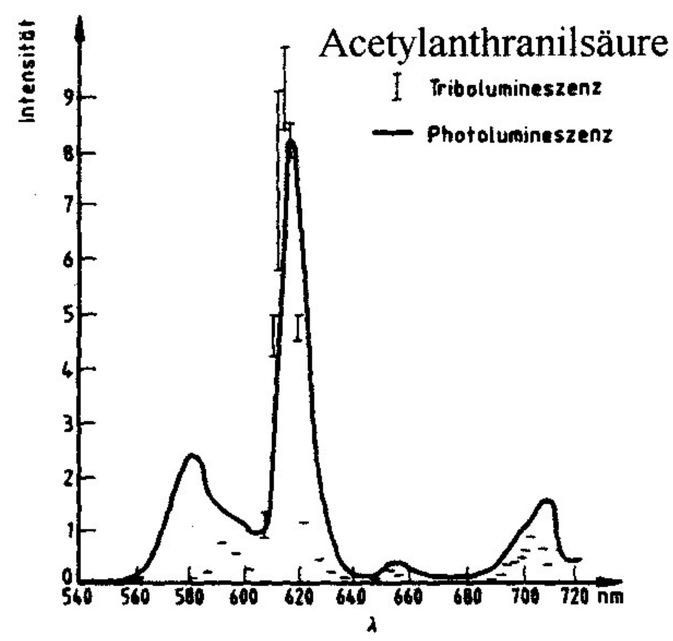
$$
\begin{aligned}
\Delta t &\approx 2 \cdot 10^{-6}\,\mathrm{s} \\
v &= 250\frac{\mathrm{m}}{\mathrm{s}} \\
s &= v \cdot t \\
&= 250\frac{\mathrm{m}}{\mathrm{s}} \cdot 2 \cdot 10^{-6}\,\mathrm{s} \\
&= 0,5\,\mathrm{mm}
\end{aligned}
$$

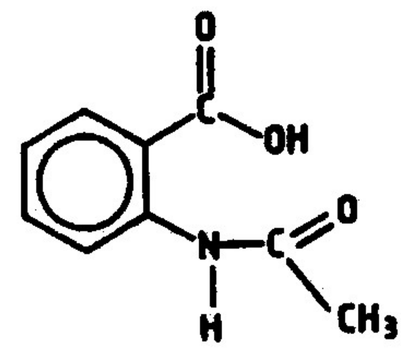
7 Other remarkable substances





- Mangan endowed Zinc sulphide has a red light.
- You can observe the lightest light in the substance $TEAEuD_4$ *(Trie-thyl-ammonium-tetrakis-dibenzoyl-methanato-europat III)*, an europiumcomplexcompond which even by ribbing with a glassstick on the vessel wall shines dark red even by day-light.
  The luminosity is a superposition of the triboluminescence and the photoluminescence spectrum.
- Anilinchlorid has a very light light, violet, N_2 is responsible, too.





N-Acetylanthranilsäure

- N-Acetylanthranilacid has the lightest light, it's blue.
- Further substances are
  quarz, copper sulphate, flouring, uranium nitrate, glucose, lactose, maltose, ghramnose, tartaric, ...

8 Another interesting phenomenon: Adhesive bands

By pulling the bands from the base you see a blue light. It's again the stimulation of N_2.

Explanation

By sticking the bands on the base, some electrons cross either to the base or from the base. Responsible are electrical forces by the base or the glue. Different charged areas develop. By pulling air comes between and analogous to the sugar you have a separation of charges. If the electrical field is high enough sparks exist and you see a continuous light.

9 Uses of the triboluminescence

- Measure of pollution or concentrations, even quantitative
- Examinations of minerals
- Analysis of complicate crushing processes
- Processes in walls

You can see, the triboluminescence is not only a nice phenomenon, you really can use it. Even in industry for crushing mills sugar was used, now Zn:Mn is used instead of it, because it doesn't glue!