

# Curriculum for a 10<sup>th</sup> grade physics education course based on project-oriented teaching via solar cookers.

Hezi Yizhaq<sup>1,2</sup> and Daniel Feuermann<sup>1</sup>

<sup>1</sup>Swiss Institute for Dryland Environmental and Energy Research,

Jacob Blaustein Institutes for Desert Research, Ben-Gurion University of the Negev, Sede Boqer Campus,

<sup>2</sup>Sde Boker Environmental High School

Midreshet Ben-Gurion 8499000, Israel.

e-mail: H. Yizhaq [yyeh@bgu.ac.il](mailto:yyeh@bgu.ac.il), D. Feuermann [daniel@bgu.ac.il](mailto:daniel@bgu.ac.il)

This curriculum is intended for students with emphasis on science in the Sde Boker Environmental high school. It is a two-semester course with two academic hours dedicated per week.

## A. Subjects

- Black body radiation and spectrum, visible light, infrared radiation
- The solar spectrum, solar radiation: direct (beam) and diffuse radiation
- Properties of light
- Light-matter interaction: absorptance, reflection, transmission
- Fresnel reflections of light transmitting materials (glass, plastic)
- Basic heat transfer mechanism (radiation, convection, conduction)
- The greenhouse effect
- Optics: concentration of sunlight via mirrors – spherical and parabolic mirrors
- Solar geometry, intercepted radiation (cosinus effect)
- Low temperature cooking vs. high temperature cooking
- Design of a solar cooker (concentrator, box cooker, or panel cooker)
- Instruments: thermometer, solarimeter, voltmeter
- Testing of the cookers, efficiency, optimization

The depth into which a teacher may go for each subject matter depends naturally on the level of students taking the course, on the demands by the Ministry of Education, or by the school policy. Below are some general outlines that the authors felt are necessary and suitable for the tenth-graders in this school. Students taking such a course have opted for a learning orientation with emphasis on the subjects of physics and mathematics. The high school offers different directions such as science or humanities. At the end of the four year study program (grades 9-12) the students are being tested in their respective fields and obtain a diploma (matriculation) where their chosen subjects obtain a significant greater weight than other subjects.

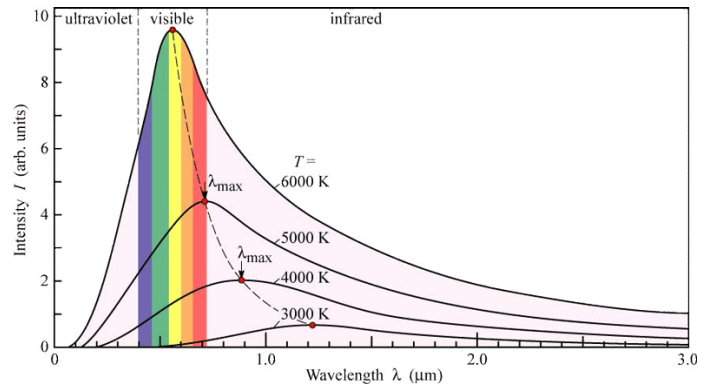
Towards the end of the first semester, students start to develop ideas for designing and constructing a solar cooker, based on available material with the teacher guiding the student to a 'doable' design, given the amount of time and resources available. The actual construction can start in the second semester, partially outside or in addition to the regular class hours. This additional time depends on the type of the solar cooker that was chosen where the panel cooker is the easiest one (~4 academic hours). The box solar cooker needs more time for designing and construction (~12 academic hours) whereas the

concentrator is the most demanding one among the three types. It needs more careful design and construction and much more time (~18 academic hours) depending on the students skills.

## B. Detailed outline

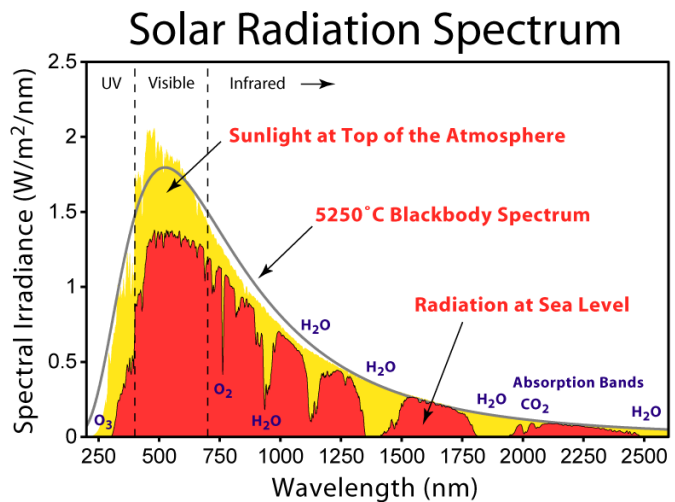
### Black body radiation:

Every material body radiates according to its temperature. An ideal body (black body) radiates according to Planck's law. A non-ideal body radiates with an emissivity that is material specific. This emissivity (measured in relation to the black body) can be so-called 'gray', i.e., the emissivity is independent of spectrum, or it can be spectrum specific (function of wave length). "Visible" light is the light that our eyes are sensitive to it – a result of evolution over millions of years. Infrared (IR) is no different, except we don't see it – some animals do "see" it or rather sense it, e.g., snakes. Example: a bathroom heater (or hot ambers from a fire) will look red as its temperature is such that some radiation emitted is in the visible (red) while most of it is in the IR.



### The solar spectrum:

It is a nearly black body spectrum, but, as it goes through the atmosphere, several spectral bands are reduced as some of the radiation is reflected and absorbed in the atmosphere. (The reason the sun looks yellow is that much of the blue is scattered causing the sky to appear blue, while the direct light from the sun lacks that blue part and therefore looks more yellow).

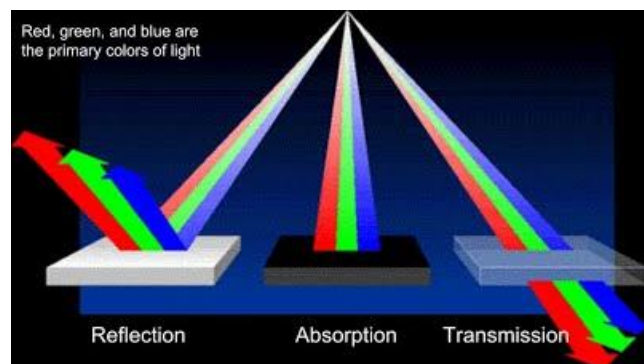


### Properties of light:

Light (radio magnetic radiation) behaves like waves. Transmission and reflection can be explained using the wave theory. For explaining photovoltaic devices, the particle nature of light is better suited. This, however, is not discussed in any details, as this would be too advanced for high school.

### Light-matter interaction - absorptance, reflection, transmission:

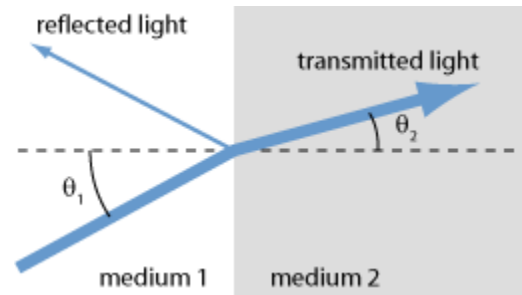
These properties are strongly material and spectrum dependent. Example: aluminum foil (highly reflecting in the visible to far infrared), white paper (highly reflecting in the visible and NIR, but



absorbing – basically black - for far IR), glass transmitting in the visible but neither in the ultraviolet nor in the far IR.

### Fresnel reflections:

Transparent (dielectric media) reflect some of the radiation as function of the index of refraction – best explained as the ratio of the speed of light in vacuum to the speed of light in the medium. Fresnel equations are optional.



### Basic heat transfer mechanism

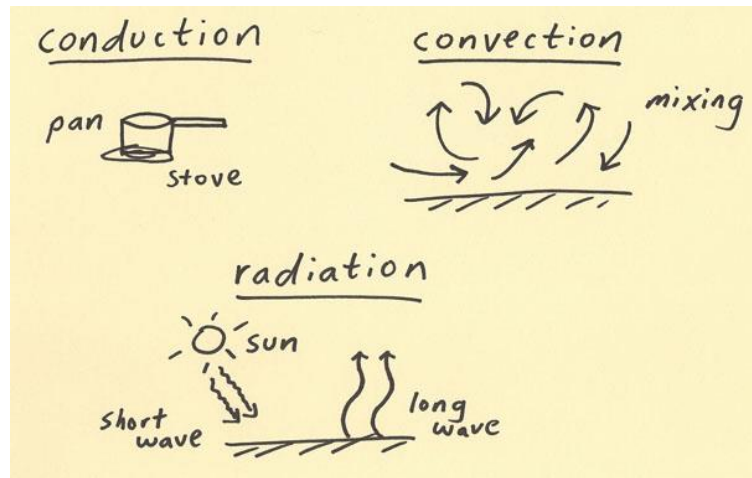
#### (radiation, convection, conduction):

Heat is transferred via radiation leaving a body, traveling through space and arriving at a second body. Concept of intercept (including the cosine of the angle between the radiation and the normal on the surface). Concept of view factor (but only qualitatively).

Convection – explained with help of conduction at the air – material interface, then forced removal (by air flow) of the heated air away from the surface.

One could add here natural convection – but that is maybe too much for this level.

Conduction is the simplest and most easily understandable form of heat transfer. It is intuitively clear that energy flows from hot to cold. Concept of thermal conductivity with examples of good conductors and insulators, e.g., copper rod, Styrofoam. Units for energy (Joule), power ( $W=J/s$ ), radiation flux ( $W/m^2$ ), heat transfer ( $W/m^2/degree$ ), and conductivity ( $W/m/degree$ ).

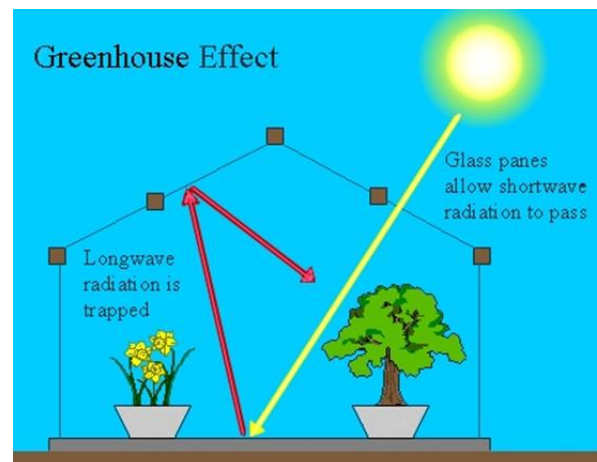


### Greenhouse effect:

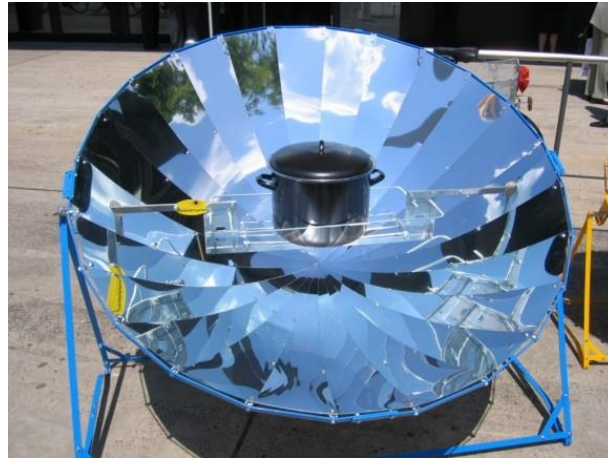
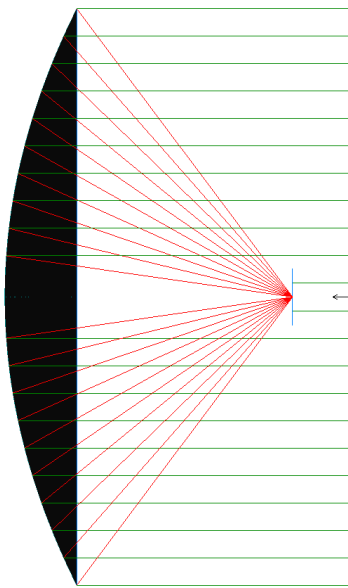
Trapping thermal radiation because of glass (or plastic) transmission being a function of the spectrum. Glass is opaque for far IR, but transparent for solar radiation (including the near IR, the non-visible part of the solar spectrum). A significant effect (often forgotten) is that the glass enclosure suppresses convection (natural or caused by wind).

### Optics:

Concentration: purpose of concentration is to reduce area for heat loss. For a given desired temperature of a target, the heat loss from that target is a function of the surface area ( $\text{Heat Loss} = UA \Delta T$ , where  $U$  is the overall heat loss coefficient,  $A$  is the area



of the surface that is losing the heat, and  $\Delta T$  is the temperature difference between the surface and the surroundings – simplification is being made that surroundings are at a uniform temperature, the view factor to the surroundings is unity, and radiation heat transfer can be treated as a linear phenomenon which is o.k., if the temperature differences are reasonably small compared to the absolute temperature, all this may be a bit too much for the high school level but perhaps it can be explained in general terms), e.g., for a high temperature such as for frying, putting in the same energy on a smaller surface can achieve this goal. Thus concentration of solar energy becomes necessary. A spherical lens or a spherical mirror can concentrate sunlight, but if we want high concentration, there are better shapes. All shapes incur aberrations; however, the parabola removes spherical (or first order) aberrations and is the preferred concentrator in most concentrator applications.



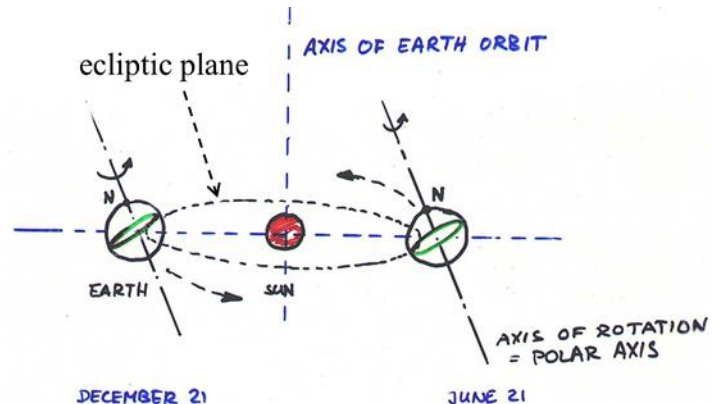
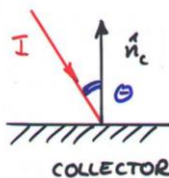
### Solar geometry

Explain the origin of the seasons – due to the tilt of the earth's axis of rotation relative to the earth-sun plane (the ecliptic plane). Intercepted radiation is a function of the angle between the radiation and the normal to the plane.

RECEIVED RADIATION:

$$I_{\text{received}} = I \cos \theta$$

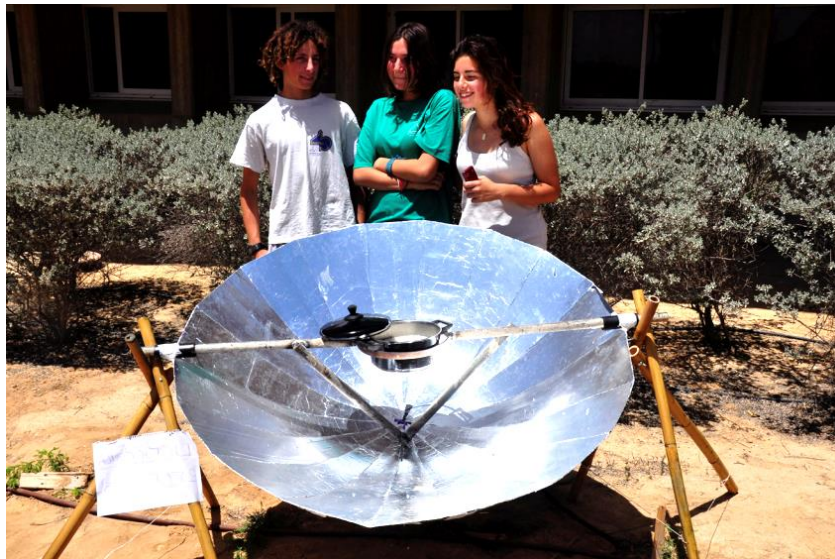
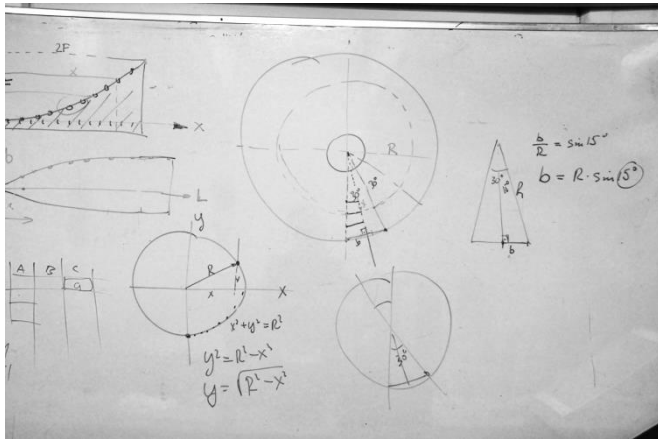
$\theta$  = INCIDENCE ANGLE



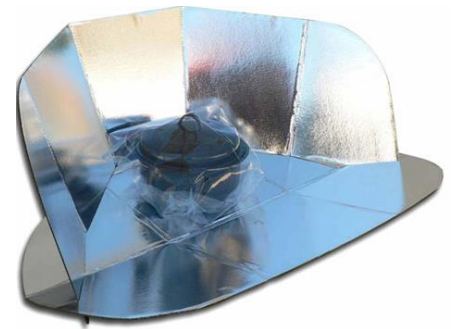
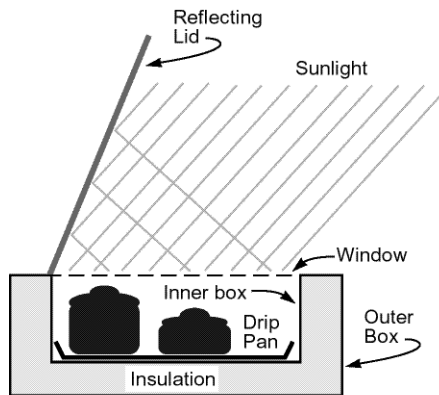


## Solar cooker construction

How can one build a large shape inexpensively? Flat mirror pieces bent in one direction only, spliced together to form the desired shape. We teach the functions and design using excel spreadsheet to determine the correct 'petals' that will approximate the actual paraboloid or sphere. See examples. Conclusions from one of the courses where students built a concentrator, was that it takes too long to build in class.

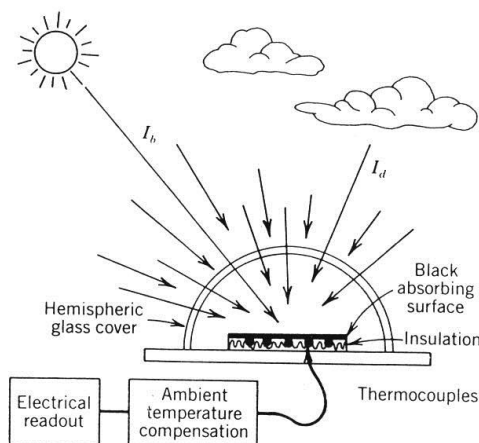


Alternatively one can make a box cooker... relatively easy: box in a box, insulation, glazing, Aluminum foil on flat cardboard for the mirror, or one can make a panel cooker which is the simplest solar cooker.



### Instruments:

How does a solarimeter work? Two types – based on a photovoltaic device or measuring the temperature of a ‘heat trapping device’. Thermometer – a calibrated device (e.g., based on expansion of a liquid as function of temperature) in thermal equilibrium with a medium the temperature of which we wish to measure. Voltmeter – measures the voltage ( ... I guess it gets a bit too much to go into details?) for example of a battery, giving some indication of the potential for driving a current. Or the potential of a column of water creating a pressure – the higher the column the higher the pressure, and the stronger the flow when making a hole in the bottom of that column.





### Testing the cookers:

How to define efficiency of a cooker? What is more important? The speed at which the cooker heats up or the stagnation temperature (what is it?). How can one measure it? What is a thermocouple, how does it work? All can only be explained phenomenologically.

By testing the different cooker constructions in parallel (at the same time), competitions between the different constructions and designs, can be initiated, something the high school students like to do.

