Due to the COVID-19 pandemic, the 25th International Physics tournament was held as a digital event on Zoom, on March 26th, 2020.

15 teams competed in the digital event, 6 teams from Israel and 9 from abroad. The countries who competed in the event were Hungary, Spain, Canada, Argentina, Slovenia the UK and Israel. Each team ranked its peers according to the safe description and a video demonstrating the action of the safe.

The top three teams were:

1st place  —  Gimnazija Želimlje, Slovenija

2nd place  —  The Schwartz/Reisman Institute for Theoretical Physics, Israel

3rd place  —  Colegio Retamar, Spain
Safes Descriptions

1st place – Gimnazija Želimiše, Slovenija

Induction Ram
1. task

Physical background: induction, electrical circuit with a diode and a capacitor.

Given props: capacitor, LED, magnet, small metal rod, 3 wires.

In the safe there is a hole around which a 2400-turn coil is positioned. As shown in the diagram, we connect the coil in a series circuit with the capacitor (470 µF) and the LED.

![Diagram 1: Correct layout of the components on the main face of the safe and wiring of the charging circuit](image)

We charge the capacitor with induction; we put the magnet on the metal rod, with which we perform quick pulls through the coil creating induced voltage. When the LED is correctly oriented, the capacitor gets charged with every pull we make. Around 10 pulls are enough to get the capacitor charged to 3V.
Diagram 2: Increase of voltage on the capacitor.
Then we take the capacitor out of the charging circuit and connect it to the voltage controlling sockets above the coil. Depending on the voltage of the capacitor, the corresponding LED light will turn on: 0V, 1V, 2V or 3V. To advance to the next task, the voltage has to be at least 3V.

Wires used to connect the first circuit are too short to directly connect the coil to the controlling sockets. That is why the competing team has to use the capacitor.

2. task

Physical background: Bernoulli’s equation (hydraulic ram).

Given props: a plastic container with water (~ 3 dcl).

There is a small hole on top of the safe, in which a movable tank is situated (it can be raised). On the bottom it is connected to the safe with a tube. This tube goes to the first T-joint inside the safe. The second output of the T-joint is open and enables water to exit the safe. The third output is connected to a pressure chamber – a plastic bottle, in which a metal ball acts as a one-way valve. The pressure chamber is also connected to a Cartesian diver with a tube.
When we pour water in the tank and raise it above the safe, water goes through the safe and out. If we close that output with a finger, the pulse of hydrostatic pressure causes the chamber pressure to increase slightly each and every time. Some water gets inside the chamber, but the increased pressure prevents further water irruption.

We increase the chamber pressure further by repeating the act of letting the water flow through and stopping it quickly with a finger. In accordance with the Bernoulli's equation, every time we stop the water flow, the kinetic component of the equation goes to zero and the pressure increases drastically. Every pressure pulse we create opens the one-way valve and increases the pressure in the chamber.
Diagram 4: Increasing pressure in the pressure chamber.

When the pressure in the chamber and the Cartesian diver increases enough, the Cartesian diver dives in and intercepts the laser beam on the photodiode. This activates the mechanism which throws out the key that is used to unlock the safe.

Diagram 5: Appearance of the safe.
Instructions for the Crackers 1.0

Phineas and Ferb decided to use force to open the safe. They tried using a battering ram, but as expected, they were unsuccessful.

1. task

If you want to open the safe, you have to use the appropriate ram. For the first task, construct it out of the added components: LED, electrolytic capacitor (be careful of the orientation), 3 connecting wires, a metal rod with a magnet and a built-in coil.

With the help of these components you have to bring a voltage of 3V to the controlling sockets above the coil. If the voltage is lower than 3V, the corresponding LED will turn on (0V, 1V, 2V). If the voltage is higher than 3V, the green LED will turn on. When the task is solved, a laser will light up by the Cartesian diver.

2. task

To solve the second task, only a few decilitres of water are needed. When used correctly, the Cartesian diver will dive and interrupt the laser beam. That is how you get the key you need to open the safe without force.

When using water, please be careful not to spill it over the safe. You are not allowed to turn or move the safe in any way.
2nd place
— The Schwartz/Reisman Institute for Theoretical Physics, Israel

"The Schlieren Effect" Safe Description,
Ilana Kats, Daniel Peretz, Amir Kedem and Aviv Zeitak

https://www.youtube.com/watch?v=ioJKDQqhCdY&t=1s
Safe description:

The safe includes two tasks. In the first one, the squad is given 5 boxes which contain different resistors. They need to arrange the resistors in the way that the current in the upper electrical circuit will be the highest that possible. This task is based on Wheatstone Bridge and series and parallel connections.

In the second task the squad needs to find out which of the heating elements are working by using the Schlieren Effect. In this task the squad has to use the flashlight that they get after the first task, the planar mirror and the pinhole.

Task 1:

The squad is given 5 boxes which contain resistors. Each color represents a different resistance value – the yellows are the least resistant, the cyan is medium and the magentas are the most resistant. The goal of this part is to create the highest current in the upper electrical circuit by creating the lowest total resistance of the same circuit. To achieve this goal, the squad needs to discover which of the resistors are higher in value and which are lower by using a Wheatstone bridge. The Wheatstone bridge is made up of a potentiometer connected in a parallel connection to a permanent resistor and to a test resistor (whose resistance we want to evaluate) that the squad needs to change between the measurements (scheme 1).
It is possible to divide the potentiometer into two different resistors (scheme 2). The resistance ratio between those resistors is equal to the length ratio between the two parts of the potentiometer divided by the sliding contact. When the voltmeter shows 0, the potential between resistors 1 and 2 is equal to the potential between resistors 3 and 4. Each color represents a different potential (scheme 2). It can be seen that the voltage on resistor 1 is equal to the voltage on resistor 3 and the same with resistors 2 and 4. Because the voltage on the part where the voltmeter is connected is equal to 0, the current in this part is also 0. Due to that, this electrical circuit can be related as a simple circuit including a parallel connection.

\[
\begin{align*}
    v_1 &= v_3 \\
    v_2 &= v_4 \\
\end{align*}
\]

Now we divide the two equations and get:

\[
\frac{R_1}{R_2} = \frac{R_3}{R_4} = \frac{L_1}{L_2}
\]

Now when the squad knows which resistor is the strongest and which is the weakest, they need to arrange them in the upper electrical circuit in a way that the current in this circuit is the highest possible (all the LED lights are on). To get the highest current, the total resistance of the circuit needs to be the smallest. When connecting a very small resistor to a strong one in a parallel connection, the total resistance is approximately equal to the resistance of the smaller resistor. Because the total resistance of series connection is the sum of all the resistors connected this way, the squad has to place the smallest resistor in series and the two strongest resistors in parallel.

The circuit should look like this when solved:
Task 2:

After the squad solves the first task, a door opens. Behind that door, they discover a big switch that turns on the heating elements, a flashlight and 8 smaller switches that open the safe.

In this task, the goal of the squad is to find out which of the 8 switches should be on and which of them should be off. The switches match the heating elements – when the squad finds out which of the 8 heating elements work, they will know the final code.

The first thing the squad needs to do is to turn on the heating elements, then they need to place the flashlight on the safe where the light is pointing on the regular (planar) mirror. Now, the squad must place the mirror 120 cm from the safe in a way that the light is focused on one point on the surface of the safe. After they focus the light, they need to adjust the angle of the regular mirror so that the light will pass through the pinhole. The minute that the squad manages to adjust the mirror in the right way, they will see the schlieren effect - a picture on the wall in which they will be able to see the warm air rising from the working elements. The last thing that left is to enter the code and the safe will be open.

The Schlieren Effect:

Hot air is less dense than normal air, and it has a different refractive index because the refractive index depends on the density of the medium.
Light rays that are coming into the parabolic mirror from a source are reflected back to a single point where the rays meet. When placing the source of light in a distance of two focal lengths from the parabolic mirror, the reflected rays are focused back to the same point.

It is important that the light source will be a point source if we want to get a clear picture. When we put in the way of the rays to the parabolic mirror a medium that is different from regular air (like hotter air), the rays will bend and won’t travel back to their original starting point.

The schlieren effect uses the fact that hot air has a lower refractive index than normal air to visualize hot and cold air. A filter is used to increase the contrast between the shadow and the light. Mostly, a razorblade is used as a filter, but in our case, it is the borders of the pinhole. The bent rays are blocked by the safe wall and don’t get to the picture. Due to that, we get darker areas in the picture that enable us to see the invisible.

In our safe we use an optical fold by a regular mirror:
**Card For The Safe Crackers**

The year is 2077 and you are at the Tyrell Corporation Headquarters. Your role, as Blade Runners, is to spot the replicants- fake heaters that humans can't distinguish from real ones.

The machine in front of you isn't only designed to reveal fake heaters, but also to recognize advanced Androids of model Nexus 6.

Your goal, in addition to identifying the real heaters, is to prove that you are indeed real humans by opening the safe.

You are given 5 boxes, each one containing a resistor. Each color represents a different resistance.

How can you find out which resistor has the highest resistance and which the lowest? To help you bridge the gap, you are given a special electrical circuit (a Wheatstone bridge).

Afterwards, you will have to place the resistors in the designated locations in an additional circuit, in order to achieve minimal resistance.

After completing the first task, you will get a flashlight – the flashlight that will let you see the invisible.

Seeing the invisible is not an easy mission after all, therefore in addition to the flashlight you are given two state of the art mirrors (parabolic and plane) that reveal the invisible – but only to the eyes of clever physicists!

Just before getting to the machine, you spot a riddle that is supposed to assist humans only:

*Heating elements at the foot of the mirror*

*Helped by switches shall open the safe door*

Good luck in revealing the replicants and saving humanity.

P.S

If the safe wouldn't open within 10 minutes you will be recognized as replicants and we will (unfortunately 😞) have to retire you 😊
Crackers are given a pencil and a piece of paper. One side of the box is decorated like a broken electric panel. To fix it, crackers must connect the two wires that pop out of the box to a resistance that they have to build using the materials given. The value of the resistance is written on a sticker on the box.

The crackers must draw a line of a specific length with the graphite pencil on the information sheet. The line should have the desired resistance that depends on the length and the width. The two wires that come out of the box through small holes should be placed at the ends of the pencil line to measure its resistance. The cables are connected to an Arduino that measures the resistance and shows its value in ohms on a small digital screen. If it is within the desired range, they are given a code to open a box with a combination lock, that gives them the necessary materials for the second puzzle. This first puzzle has to do with the electrical resistance of a material. This follows the law:

$$ R = \rho \times \frac{l}{S} $$

where $R$ is the electrical resistance, $\rho$ is the resistivity, that depends on the material, $l$ is the length of the conductor and $S$ is the cross-section area of the conductor. This formula tells us that the resistance is proportional to the length and inversely proportional to the cross-section area.

Crackers should know that graphite is a very common conductive material. They are given a pencil with which they can draw a line on a paper. If the crackers use the two multimeter probes to measure the resistance, they can move them closer or further apart to modify the value measured by the Arduino, which is shown on a display.

In a very short time, crackers can solve the puzzle if they know the law of resistance. However, a person who did not study physics would find it difficult to open the box because the electrical resistance of graphite is not an intuitive concept.
Second puzzle

The objective of the puzzle is to use knowledge of electromagnetism in an innovative, challenging way for most crackers. The theme of the puzzle is the Metro de Madrid (subway). They will have to build a Faraday train. Its design is based in the homopolar motor invented by Michael Faraday in 1821. It consists of a battery with two magnets attached to each of the poles. When it is placed inside a coil of copper, a circuit is created because the current flows through the magnets and the coil. This current produces a magnetic field that exerts a force on the train, causing it to move forward.

The crackers will receive two spherical neodymium magnets (at the beginning) and a AAA battery (after the first puzzle). They will have to build the train by putting magnets on each side of the battery. The poles of the magnets must have the same orientation to work (the same pole facing outwards at both sides of the battery). If they have opposite directions the magnetic force cancels and the train doesn’t move. Finally, they have to introduce the train inside the circuit through the entry holes.

This second puzzle is about magnetism. To solve it they must build an electromagnetic train. This works in the following way. When the train is inside the circuit, the electric current generated by the battery flows through that part of the coil, generating a magnetic field. This magnetic field causes a force that attracts the magnet in the front of the train and repels the magnet at the back of the train, causing the train to move forward.

Once they understand how the train should work, they should be able to build it easily. However, without understanding the puzzle, we believe that it is almost impossible that they succeed.

Safety risks

We believe there aren’t any safety risks. The current used is low voltage.
Safe cracking Instructions
(actions in green and results in red)

1. Crackers use the pencil given to draw a long, thick line on the piece of paper given.
2. Crackers take the multimeter probes and move them closer or further apart to obtain the desired measurement of resistance. The value that they are measuring is shown on the screen.
3. When the value measured is correct, the screen shows a code.
4. Crackers put the code in a combination lock to open it and obtain the remaining materials needed for the second riddle: a AAA battery
5. Crackers build the “train” by placing the magnets with the correct orientation on both sides of the battery.
6. Crackers put the train inside an opening in the front side of the box.
7. The train moves around the circuit. When the Arduino detects that the train has gone around the circuit, it gives crackers another code to open a box, revealing a prize for the crackers.

The box from above:

From the left side:
DESCRIPTION OF THE SAFE

The safe has a shape of a mobile phone with a LCD screen emitting polarized light. Right and front panels are covered with polarizer. On the upper panel there are two slits and a hole. Angle of light polarization emitted by LCD and polarizers is 90 degrees, therefore light cannot pass through.

In the safe there is a tube filled with water that goes from the top to the bottom of the safe. On the upper part the tube is opened and accessible. On the bottom of the tube there is a photoresistor covered with magnetic disc. Aim of the first riddle is to lift the magnetic disc.

When first riddle is completed ten digits appear on the screen. The goal of the burglars is to find out which four digits are the combination for the lock.

The burglars are given

- charger (It is a plexiglass box with a syringe in it and connected to the cord which can be used in a cracking process.)
- plastic dropper
- two iron nuts
- SIM and SD card (They are made of plexiglass covered with adhesive tape. The contacts in the chip are made of iron.)
Before we start the hacking process we insert SIM and SD card in the slits on the top of the safe. Adhesive tape is birefringent material, therefore light can pass the panels which are covered with polarizer and they become transparent.

To complete the first task we have to create a cartesian diver using plastic dropper and two nuts. Then we fill up the cartesian diver with water and put the cartesian diver into the water in a cylinder. When we create overpressure with a syringe, the cartesian diver sinks and sticks to a magnetic disc that is at the bottom of the cylinder. Then we must create negative pressure using a syringe in order for the cartesian diver to rise. The magnetic disc sticks on the magnet that is on the side of the cylinder and we can take the magnetic disc out.

When we lift up the magnetic disc the photoresistor gets lit up and its resistance changes. Raspberry Pi senses the change in voltage and when that happens ten digits shows up on the screen. The first task is complete.
3. In the second part of the puzzle we have to take out the SIM card and attach the magnetic disc on it. After that, we take the SD card out and tie it up with the cord from the charger.

We insert both cards together in the slit in front of the LCD screen. The two cards are connected to each other by a magnet. By using the cord we rotate the SD card and in the certain angle blue filter is created. This is because two layers of the tape, which is a birefringent material, change the direction of the polarization, for different wave lengths differently. That makes some numbers on the screen less visible and four numbers stand out. We enter the four digit code in the dial and the safe is opened.
HEMDA - Centre for science education, Israel

Name of the vault: Sfinagnet (hebrew for Magnet-ship)

Builders: Shai Rotman, Amit Laiser, Yuval Altman, Romy Anne Kramberg, Gil Greenwald

School: Hemda

Physical mechanism:

The main physical principle of the vault is magnets.

In order to successfully hack the vault, one must solve two riddles, which are presented as two distinct levels.

In the first part, there is a wooden box, with a plexiglass top, and a plexiglass ceiling which covers it. The upper face of the box has holes in it, in which one must insert magnets in a conic shape, so when the ceiling is closed, a small cylinder shaped magnet will roll inside the box to a laser sensor that will detect the magnet's movement. The hackers must understand that in order to bring the cylindrical magnet to the laser sensor, all the magnets they insert into the holes must be shaped like a truncated cone, and it has to be symmetric. They also need to understand that one side of the magnets should be north-side up, and one should be south-side up, in the opposite direction of the cylindrical magnet.
The dimensions of the box are 40x60x8 cm (including the ceiling). The box is the deck of the ship. Upon finishing the first part (the sensor detecting the movement of the cylindrical magnet), a door opens at the back of the ship, and a small sack with keys in it is given to the hackers, which aids them in the next riddle.

In the second part, there is yet another box, this time made of plexiglass, with only one hole in it. Inside the box, there are a compass, a plastic arm which blocks the compass needle from rotating in one direction and another laser sensor. The keys given to the hackers at the end of the first part contain small bars attached to the ends of the keys, which are made of steel, brass, plastic and copper. The steel key is the only ferromagnetic key, and it is magnetised, so when inserted to the designated slot, the compass needle rejects it. The hackers need to de-magnetise the key, using a hammer they get, by hitting it. After de-magnetising the key, the compass needle is attracted to the steel bar, and it moves, which allows the laser beam to go to the photoreceptor, triggering another door at the back of the ship to open, which signifies the success of the hackers at solving the vault.

The compass box is located above and behind the deck, and its dimensions are 22x22x22 cm.

Design description:

The vault is designed as a classic pirate ship. Its length is 120 cm, its height is approximately 40 cm, and the deck's height is approximately 25 cm. The width of the ship is 37.5 cm. At the sides of the ship there are four canons (two in each side). On the deck, in front of the first level, the Sfinagnet flag is located (which was designed by Shai). Inside the ship lie all the electronic parts. In front of the ship there is a button which upon pressing, resets the vault (it is pressed before any team begins to hack the vault).
The design of the ship was taken from the internet, and was modified to match our needs. The ship was cut by laser, as two-dimensional planes which were later glued to each other. Because of the ship's enormous size, it had to be built as two different parts with length of 60 cm.

Everything on the ship (the perforated surface, the plexiglass cube and the ship's body) were designed and cut/3d printed by us, at the makers lab at Hemda. The map at the wooden box' bottom was designed by Shai, and was cut in laser. The compass drawing in the compass box was designed by Romy, and was drawn using a soldering iron (and it took almost three hours).

The code was written by Yuval, and all the electronic parts were put together by Yuval and Amit.
The Submarine

**Students names:** Liron Goldman, Gilli Lapid, Hadar Cohen, Ofir Peleg, Amitay Minai.

**School name:** Ort Rabin Gan Yavne.

**Safe name:** The Submarine.

**Safe Decription**

- **Frame Story:**

  The Israeli Navy must launch a dangerous and remote operation in order to save the country and the burglars are divers serving in the Davidson submarine. The submarine engines have broken down while the submarine is underwater and the oxygen is running low. Team members must open the vault door to reach the switch that will operate the spare engines that will allow the submarine to continue on its orbit and perform the mission to save the country before the oxygen runs out.

- **General design of the safe:**

  The safe was built from the boards provided by the Davidson Institute and its introduction is transparent. The submarine is designed like the seabed and is decorated with shell-like ornaments, coral, etc. and a submarine painting / model.

- **The final destination of the story and the purpose of the opening**

  Burglars must obtain the code that opens the vault door and press the switch inside the vault, which will operate the spare engines that will allow the submarine to float before the water before the oxygen runs out to crew members and continue their mission.
Physical principles in the safe:

Buoyancy Principle: When a body is inserted into a fluid, the fluid exerts an opposing force on it towards gravity. This force is called buoyancy. If buoyancy and gravity compare - the body floats on the surface of the fluid. If the fluid is unable to exert sufficient buoyancy on the body and gravity exceeds buoyancy, then the body will sink into water and not float. If a body of any volume sinks in the liquid, it actually takes the place of exactly that volume of the liquid itself, and that the body balances the buoyancy force equal to the gravity acting on the fluid in its place.

Principle of electromagnetism:

Electromagnetism is a physical phenomenon that links electricity to magnetism. When a current is passed in a conductor, a magnetic field is created around it, the stronger the current, the greater the magnetic field and induced force around the conductor, and if a current does not flow, no magnetic forces are generated.

Principle of Magnetism.

Magnetism is a physical phenomenon whereby a bone exerts repulsive forces and pulls. Like electromagnetism, magnetism results from electron movement but at the sub-atomic level within the material, thus generating constant repulsion and attraction forces.

Ideal gas model:

Ideal gas is a physical model that describes material behavior in a gas accumulation state. The ideal equation of state states:

\[(\text{Gas pressure}) = (\text{gas volume}) / (\text{number of gas particles}) * (\text{gas temperature}) * (\text{Boltzmann constant})\]

\[P = (N / V) * T * Kb\]

When the glass bottle is heated, the air inside it also heats up, its volume increases and the air density inside the bottle is less than the air density outside, i.e. the ratio of the number of
gas particles to the volume of gas inside the bottle is small compared to the ratio of the number of gas particles to the room air volume. So when the bottle and the air trapped inside it (after turning the bottle over the bowl and putting the straw into the water) cool down to room temperature the pressure in a bottle is smaller than the air pressure in the room (atmospheric pressure) that is applied to the water and therefore the water is "pumped" into the bottle for pressure comparison.

Pendulum movement:

A pendulum is the object that depends on the axis and can swing freely, the pendulum movement is a harmonic motion resulting from the conversion of altitude energy to velocity energy and vice versa.

Cracking mechanism:

Puzzle # 1:

The burglars must pour the hot water from the kettle into the flask using the funnel until the flask is filled.

They have to wait a few moments for the bottle to warm up and pour the water into the bucket they receive at the beginning of the riddle.

The hot bottle should be turned over the painted water bowl and the straw nozzle should be put into the water and as a result the water is pumped into the bottle through the straw. (See ideal gas model on previous page)

After the bottle is filled with water, the burglars must pour the water through the funnel located on the vault roof and drain sparingly inside it. Styrofoam will rise (which contains a magnet), the ball will float (see buoyancy principle) into the hole located on the sides of the vault through which the burglars can take it out.
The burglars will pull the magnet out of the ball

With the help of the magnet, the additional magnets that are in a narrow row will be removed, by attaching the magnet to the sides of the row, the magnets of the magnets that are in the row will be pulled out and drawn towards the opening of the row.

Puzzle # 2:

The burglars will receive a metal hook and battery.

The magnets that were removed in the first part of the safe will be attached to the built-in reinforcing screw in the rear of the safe to create a magnetic field (see Magnetic Principle).

The copper wires will each be attached to the appropriate battery of the battery and begin to give "pulses" which will create a magnetic field (should use pulses and not otherwise because it works like a rocker, give a boost only when the rocker comes back down and here too), reject the copper ring (see Principle of electromagnetism) and the creation of oscillating motion (see pendulum motion).

Insert the hook that the burglars get through a hole in the front of the safe and try to catch the swinging copper coil.

After grabbing the coil, pull out the wrapped piece of paper on the determined coil and contain the code to open the lock.

The lock will open the safe door.

Principle of electromagnetism, magnetism, ideal gas, pressure, pendulum motion, buoyancy.

First, the behavior of gas and the effect of temperature on gas pressure must be understood to solve the first puzzle of the vault (filling the bottle with water). Further on, they must understand the buoyancy principle that will work on the polystyrene ball containing the magnet.
Later on, the burglars need to understand the principle of magnetism in order to get the other magnets out of the glass.

In the second puzzle, intruders must know the principle of electromagnetism - they must close the circuit with the battery and know how the coil will be affected by the current transfer therein and the magnetic field induced by the magnets.

The Vault solution is contingent on understanding physical principles and therefore only a person who knows these principles and learns them can solve the puzzles.
Our safe was designed and built to operate with the following physics principles: Reflection and Refraction of Light, Parallel Capacitors, Stroboscopic Effect and Electromagnetism. It is divided into two modules; figure 1 shows module 1, and figure 2 shows module 2.
**Figure 1:** From this top view, we can observe the laser beam, a fish tank with water and a laser receptor. We can also see the double bottom wall for the cabling.

**Figure 2:** From this top view, we can observe the capacitors, the electromagnetic motor (the copper coil, the magnetic rotor, the magnetic sensor) and two strips of LEDs (which simulate a strobe light). Below is a front view of the capacitors.
**Figure 2:** From this top view, we can observe the capacitors, the electromagnetic motor (the copper coil, the magnetic rotor, the magnetic sensor) and two strips of LEDs (which simulate a strobe light). Below is a front view of the capacitors.
Process of cracking

The process of cracking the box starts in the first module of the box, where we find the laser beam, which must go through the water tank, reflecting and refracting in order to reach the sensor. When capturing the signal, the second module, where the capacitors are, is enabled. When connecting them we must obtain the greatest possible capacitance, which enables the ignition of the LED strips. These leds are programmed with a frequency that is the same at which the electromagnetic motor turns. At this point, we should be able to see the code that we must place in the lock which opens the box, where the prize would be.

It should be noted that to maneuver the second module of the box, the first module must be completed effectively, and the signal must be maintained. Another important information to know is that our box is completely programmed by the Arduino programme in all the processes. We have used it for the LEDs that are outside the box; for the turning on and off at the right time; for the capacitors, since we have actually replaced the real capacitors by this programme; and finally, for the frequency of the LEDs strips.

Materials:
The materials we need to open the box are.

1. Cables: a set of cables to be able to establish the connection of the capacitors which we have used to obtain the highest capacitance.
2. A wooden board: a board which would have the instructions stuck on it, as well as a hole, to be able to repress the light rays from the outside in the second module.
**Instructions for the Thieves:**

In front of the box, we can observe a switch whose only function is to turn the laser on or off. We can also observe 4 LEDs, 2 in the first module, and 2 in the second, which are red and green. The red ones indicate that the riddle is enabled to be solved, and the green ones would indicate when the riddle is already solved.

**Figure 3:** In this front view, we can see the distribution of LEDs and the capacitor connections.

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<thead>
<tr>
<th>laser module</th>
<th>capacitors module</th>
</tr>
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<tbody>
<tr>
<td><img src="image" alt="Red LED" /></td>
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<tr>
<td><img src="image" alt="Green LED" /></td>
<td><img src="image" alt="Green LED" /></td>
</tr>
<tr>
<td><img src="image" alt="Laser switch" /></td>
<td></td>
</tr>
</tbody>
</table>

The layout shows the connection points for the LEDs and capacitors.
Milestone Institute, Hungary

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<tr>
<th>SCHOOL NAME</th>
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<tbody>
<tr>
<td>Sándor Kollarics</td>
<td>+36 20 422 0070</td>
<td><a href="mailto:kollarics.sandor@gmail.com">kollarics.sandor@gmail.com</a></td>
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</tr>
</thead>
<tbody>
<tr>
<td>1 (CONTACT)</td>
<td>Gergely Farkas</td>
<td>+36 30 5614393</td>
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NAME OF SAFE: We couldn’t resist

MAIN PHYSICS PRINCIPLES NEEDED TO CRACK THE SAFE (WHAT THE ‘BURGLARS’ SHOULD KNOW IN ORDER TO BE ABLE TO BREAK INTO THE SAFE AND WHY SOMEONE WHO IS NOT STUDYING PHYSICS WILL NOT BE ABLE TO OPEN IT BY TRIAL AND ERROR OR COMMON SENSE)

The safe is based on the two main topics are the "Basic phenomena of light" and "Direct current circuits". First, the burglars should solve a DC circuit problem called the "Resistor Riddle". To solve this problem, they need to recall what they’ve learned about resistors connected parallel and in series combination. Using six independent switches, they can determine the resistance of the six unknown resistors. Using the six values, a 3-digit code can be computed. The reason why this is more than trial and error problem is twofold. First of all, the number of resistors gives a huge number of combinations, therefore it is unreasonable to try without thinking. And second, the crackers won’t know which state of a given switch gives parallel and serial connectivity. Hence, they need to remember that what happens if two resistors are connected this or that way. This is basic physics knowledge and there is no need for formulae. People who are not familiar with this will not able to decide how to resistors are connected and that is the only way to determine the resistivity values.

The other part is the optical riddle where a laser beam must hit a photoresistor to lower its resistance under a certain value. The resistor is connected in series with an ohmic resistance and a DC voltage is applied. The voltage on the ohmic resistor is measured and if it hits 2V then a relay connected to it turns on the switch of another DC circuit which consists of an electric lock and a power supply. Once the laser hits the photoresistor the voltage on the other resistor goes up and via the relay the lock opens.
• Are there safety issues with what you intend to build? If you plan to use a fire source, high-energy lasers, etc., how will you ensure that no damage will be caused to people and the environment?

To the best of our knowledge, no safety issues are present in our safe. In the optics riddle, a low power laser (pointer) is used, but we intend to meet the appropriate safety class. As power supply, a low voltage DC source is built in the safe. There is no possible way for the burglars to touch this supply circuit, but even if they could the voltage needed to drive the laser is too low to cause any problems.
Here we present a 2D view from the upper side, and below that, another from the side.
Our safe is a 4-wheel carry-on luggage. To stick to the given instructions, we build a wooden box with the given dimensions, and plexiglass (PMMA) upper cover. This upper cover is the door of the safe and can be opened in two steps. In the box, two riddles can be found. The "Resistor riddle" can be seen from the beginning. Solving this, the burglars get a three digit code that opens a classical lock. If the lock is opened, a cover can be removed from the other half of the door, revealing the second part, the optics riddle.
Placing plane plexiglasses (PMMA) with different thickness in the right order, the burglars can move the light beam up or down in the z-direction. The laser and the detector are not at the same height therefore understanding the effect of the plane-parallel plates the beam can be leveled properly. The laser is driven by a power supply built in the box that can be switched on by pulling the handle of the luggage.
Giving our wooden box a luggage like outlook and using the wheels and the handle to open it tells a story and that is why we chose this structure.
<table>
<thead>
<tr>
<th>ACTION</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>The student remove the cover from the first part (resistor riddle).</td>
<td>The resistor riddle can be seen from above.</td>
</tr>
<tr>
<td>They connect the resistance meter (multi-meter, a.k.a. battery checker)</td>
<td>The device shows the resistance of the six resistors connected in an unknown configuration.</td>
</tr>
<tr>
<td>They start to set the switches</td>
<td>The resistivity shown by the device changes.</td>
</tr>
<tr>
<td>Using physics knowledge they figure out that if all resistors are connected in series or in parallel, they observe extremum of resistance. So they choose extremal settings.</td>
<td>They observe external resistance (maximum for all 6 connected in series and minimum for all 6 in parallel.)</td>
</tr>
<tr>
<td>They change ONE switch and measure the new resistance.</td>
<td>The resistivity changes and using the previous value and this, the crackers have two equations and variables. All needed formulae and a calculaltor is available.</td>
</tr>
<tr>
<td>They set back the switch and repeat the previous step with every individual switch.</td>
<td>They determine the second value this way and so on.</td>
</tr>
<tr>
<td>Now they have the six values and put them in a simple equation and get the 3-digit code.</td>
<td>The 2nd part, the optics riddle can be seen from above.</td>
</tr>
<tr>
<td>Pulling out the handle, the power switch closes and the lasing starts.</td>
<td>The crackers see where the beam goes and can start to figure out how to solve the task.</td>
</tr>
<tr>
<td>Removing, rotating and putting back the PMMA plates the beam is leveled up or down depending on the orientation.</td>
<td>The burglars understand the effect of the plates and can decide where to move the beam.</td>
</tr>
<tr>
<td>Putting the plexiglasses with different thickness (and so different displacement) in the right order, the light hits the photoresistor and lowers its resistance.</td>
<td>The electromagnetic lock opens and the &quot;luggage&quot; is open.</td>
</tr>
</tbody>
</table>
In the resistor riddle, we have to make sure that a small error in the measured values has no impact on the result (the determination of the 3-digit code). Therefore we need to carry out several measurements and set a proper tolerance level.

In the optical riddle, the bottleneck is the proper intensity on the detector. Therefore our most important experiment is to determine the threshold level, at which the detector response is high enough to open the electric lock. We would like to build a system where a certain intensity must hit the detector

The Resistor Riddle

Enter the value of the following expression onto the padlock:

\[ 10 \left( R_3 + R_4 + R_6 + \frac{R_1 R_2 R_5}{R_1 R_2 + R_2 R_5 + R_1 R_5} \right) = ? \]

How to use the switches?

The six switches are allocated to six resistors. Each switch selects if the allocated resistor be put into pool A (Position DOWN on the switch) or pool B (Position UP on the switch). The resistors in pool A are then connected in parallel and the resistors in pool B are connected in series and finally the two pools are connected in series (see fig. 1).

Disclaimer: When all switches are set into UP position, the resistance measured is infinity.

1. Figure
Dear Burglars, welcome to our truck. The name of the truck is the “Vault-rotor”. We are a motor company and we have heard that you are an amazing car mechanics. We would like to give you a Once in a lifetime opportunity. We have a problem with our engine and you are the only ones that can fix it!

The main physical principles that are required in order to crack the safe are:

**polarization** - light is an electromagnetic wave. An electromagnetic wave is a transverse wave (its oscillations are perpendicular to the direction of the wave) and if we pass unpolarized light through a linear polarizer, only the part of the light that is in the same alignment as the polarizer will pass through. We can create a polarizer from different kinds of plastic. The principle of operation of the LCD screen is based on linear polarization. Many of the behaviors of polarizing materials go against the usual behaviors of materials with light - therefore a puzzle based on this principle cannot be solved by trial and error.

**The principle of the operation of LCD** - The screen is constructed of a liquid-crystal structure and polarizers. Liquid - crystals changes the polarization of light depending on the electric field applied to them. In LCD's linearly polarized light is transmitted through a liquid crystal layer. The liquid crystal layer is located between the incident linearly polarized light and a linear polarizer that is placed in front of the screen. The polarizer is perpendicular to the plane of polarization of the incident light which allows only light that its polarization had changed by the liquid crystal to be emitted from the screen. The amounts of light passing through the polarizer is controlled by the voltage applied on the liquid crystal.

**Speaker** - The speaker works by vibrations of a thin membrane that causes air fluctuations, which drive the eardrum and allows us to hear. This is how sound waves propagate. A resonance box can be used to increase the volume.
Resonance box- A small, semi-enclosed or closed space that increases the amplitudes of waves by constructive entanglement.

Magnus effect- A physical phenomenon in which an object rotates around one of its axes while in medium (liquid or gas), while the object (or its surroundings), moves in one of the other axes (perpendicular to the axis of rotation), resulting in a vortex that creates a force perpendicular to the direction of rotation.

Flettner rotor- Is a propulsion method performed by cylinders that rotate under air flow. The Air flow generates a lifting force that is perpendicular to the air flow and is used to propel the ship - the turbine operates according to the Magnus effect.

Visual structure of the safe:

Breakout - Arrange for a successful breakout

*It is not important to solve the puzzles in a specific order. After solving each puzzle, the burglars will receive a 4-digit code. The burglars will put together the 4 digit code that they received by the order that will be described to you now (the sum of the first digit from the
first puzzle and the first digit from the second puzzle will give you the first digit to the code of
the safe and so on with the second, third and the fourth digits of the code).

Our race car got stuck on the racetrack. It has two problems that need to be fixed to make it
continue the race.

First puzzle - "Exhaust" riddle: The first fault that needs to be fixed is the "Exhaust". You
have the following equipment: a cardboard cup, a wooden stick, a motor connected to the
phone and a "perforator" (a pointed rod) – all of the materials are inside a box that is located
outside the safe itself. To repair the exhaust, a hole in the wooden stick must be punched
with the "perforator" that is provided by the car repair department. In order to continue
solving the puzzle, insert the motor hinge into the wooden stick, and hold the wooden stick
against the cardboard cup. The phone plays the code in loops, and the speaker you
constructed will enable you to listen to the sound coming out of the resonance box - the
cardboard cup, while the room is quiet.

The second puzzle - the "engine" riddle: The second fault that needs to be fixed is the
"engine". You have the following equipment: A trolley that is connected to an electric motor
with its shaft connected to a translucent cylinder (a plastic bottle). The trolley is inside the
safe. The car engineers will have to find a way to place the trolley in front of the polarizer
filter so that the transparent plastic cylinder will "cancel" the polarization and allow them to
see the code on the screen. They will do so by a blowing on the translucent cylinder. There is
a slot in the back wall of the safe (along with a mesh). The burglars will need to blow out
through the slot (which has a mesh on it), perpendicular to the trolley. As soon as the trolley
arrives in front of the polarizer, one burglar has to look through the cylinder and the polarizer
into the screen, and the burglar will receive the following 4 digits of the code to the safe

The safe can be cracked with the solution of both puzzles.
Ibstock Place School, UK

IPS – Let’s Get Quantum Physical

Safe Instructions and Description

Description:

This year, IPS is proud to present our safe – ‘Let’s Get Quantum Physical’ to the International Final Weizmann Safe Cracking Competition. Our safe consist of two sections and the first must be completed before the crackers can progress to the second. The first puzzle is based on the discrete emission spectrums from different gaseous elements when a high current is passed through them. The second is called the ‘Conservation Cube’ and is a decay chain of a negatively charged Kaon spanning a 3D cube. The crackers have to deduce the missing subatomic particles using the principles of momentum, charge, baryon number, lepton number and strangeness conservation.

Enjoy

RULES:

1. TO PASS THE FIRST CHALLENGE, ONE MUST IMPUT THE ATOMIC NUMBER FOLLOWED BY THE ATOMIC MASS (4S.F.) OF THE ELEMENT.
2. THIS WILL RELEASE THE CONSERVATION CUBE FROM THE BASE OF THE SAFE. IT MAY BE LIFTED UP CAREFULLY TO GAIN ACCESS TO THE KEYPAD.
3. DEDUSE THE MISSING SUBATOMIC PARTICLES AND IMPUT THE CORRESPONDING CODE TO UNLOCK THE VAULT DOOR.
4. DO NOT DROP THE CONSERVATION CUBE, IT IS EXTREMELY FARAGILE.
Blich high school, Israel

Black Boxinator 3000
Items given to safe crackers:

- Paper Clip
- Zip Tie
- Short stick with a handle
- Paper Towel
- Water
- Steel Wool
- Lighter

First Step - Home Made Crankshaft:

The mechanism is comprised of two wheels mounted on an axis and a motor adjacent to the wheels that generates electricity once the wheels are turned. The motor is connected to an Arduino that checks for a certain amount of voltage over time. The wheels are turned by crafting a faux crankshaft out of a paper clip and connecting it with zip ties to the axis the wheels are connected to. The next step is to connect the short stick to the crankshaft and move the stick in a linear motion, the crankshaft then converts the linear motion into circular motion and spins the wheels. Once the wheels have generated a sufficient amount of voltage the Arduino will display the code to a lock that unlocks the second step.
The physics:

The physics behind this riddle is split into 2 parts: a theoretical part and a mechanical part.

The theoretical part:
If the safecrackers look closely they will see a small DC motor, with the axis lightly pressed against a large rubber wheel. The safecrackers will know that they need to create voltage between the 2 motor wires, and in order to do so, they need to understand that they must do as follows:

spin the motors axis, which will be spun if they manage to spin the large rubber wheel, which will only be spun if they manage to spin the large axis that is currently “bare” (nothing connected or taped to it).

A small motor as we are using is comprised of permanent magnets connected along the edge of the motor, with a coil running through the middle. Said coil is attached to the motor axis, and whenever a current carrying conductor is placed in a magnetic field, the conductor experiences a force which is perpendicular to both the magnetic field and the direction of current, which in this case will spin the coil and axis.

If the opposite is done, and the motor axis is turned, this will change the magnetic field on each point of the coil, which will create a magnetic flux along the coil. As per Faraday's law of electromagnetic induction, whenever a conductor is forcefully moved in an electromagnetic field, an emf (electromotive force) is induced across the conductor. If the conductor is provided a closed path, then the induced emf causes a current to flow. In our case, the emf is the voltage between the 2 motor wires.

The mechanical part:

Now that the safecrackers know that they need to spin the large axis, they need to solve the problem of doing so with the safe door closed, and with only a small hole in the safe, and a stick that is long enough to reach the axis. Because of the small diameter of the hole, they can only move the stick in a linear fashion (back and forth), and they need to find a way to make that motion translate into the rotation of the axis. The translation from reciprocating (linear) motion to circular motion can be done using a crankshaft that the safecrackers can create using the given paperclip and connect to the axis using the given zip ties.
How a crankshaft works:

As seen here, the crankshaft is simply an extension, with a slight offset, of the “main axis”, and allows reciprocating motion to rotate the main axis with use of a connecting rod. As seen in the diagrams, there does need to be a certain amount of freedom in movement for the connecting rod, to allow the crankshaft to rotate fully, but the slider itself moves in a completely linear fashion. At the edges of the sliders movement, when the connecting rods plane correlates with that of the sliders movement, the crankshaft cannot generate any force. Nevertheless the crankshaft continues to spin because of angular momentum it has accumulated during the rest of the sliders movement. As soon as it passes that point of correlating planes, the force applied on the crank by the rod accelerates the rotation of the crank until the next point.
Second Step - Hoffler Tube:

Once the lock is opened the safecrackers will encounter a disassembled stand for a vial with directions on how to assemble it. Once assembled the safecrackers need to create a sound; to do so they must stuff steel wool into the bottom half of the vial at a marked location, then wrap a wet paper towel around the top half of the steel wool. Once these steps have been completed the bottom half of the vial needs to be heated with a lighter. After a set amount of time, the vial will make a sound, and a raspberry pi will pick up the frequency. If the frequency is correct an applause track will play.

The physics:

The goal of this experiment is to turn the vial to sort of a speaker. How does a speaker create sound? The front of the speaker (diaphragm) moves back and forth rapidly, which pushes the air in front of the speaker. Like that a disturbance is introduced to the air. When the disturbance reaches our ears we perceive that as sound.

In the experiment, the air in the vial moves back and forth, where the air closest to the closed end moves the least, and the air closest to the open end moves the most, causing a disturbance similar to a speaker.

To understand this further, there are two main questions to answer. Firstly, why does the air move in the way that it does? Secondly, how do the steel wool, paper towel and fire help create the disturbance?
**Why does the air move in the way that it does?**

When a disturbance is introduced to a close-end tube the air begins to oscillate (move back and forth), the air molecules at the closed end bump at the closed end and therefore can’t really move, so it stays at about the same spot. On the open side the air molecules are free to move so it moves a lot. There is a gradient between the 2 sides, the closer we get to the closed end the less the air molecules oscillates.

**How do the steel wool, paper towel and a lighter help create the disturbance?**

As we said, in order for the sound to occur a disturbance needs to be introduced, the way we introduce a disturbance is with pressure differences. We cause a pressure difference by making the closed end of the tube very hot with the lighter, and the open end relatively cold with the wet paper towel.

Now the tube’s material has a pressure difference but the air does not because is is moving too freely inside, so the pressure difference disappears quickly. To help increase the pressure difference we put a steel wool inside the tube to prevent the air moving easily.

The maximum gas molecule velocity in such systems appears approximately one third of the tube’s length from the closed end, therefore, this is where the steel wool element should be placed for the most efficient arrangement.

**About the pitch of the sound:**

The resonant frequency can be determined with first-year physics equations:

\[ \lambda = 4L \] for the fundamental frequency that a closed-end tube will make.

\[ v = f \lambda \] where \( v \) is the speed of sound in air.

\[ f = \frac{v}{4L} \]

In words: The frequency is the speed of sound (343 meters per second) divided by 4 times the length of the tube (in meters). The theoretical value is 591 Hz. when experimenting we measured 571 Hz, which can be caused by the fact that the vial doesn’t have a straight bottom.

The width of the tube doesn’t affect the frequency but would make it louder, because more of the sound wave would be created.
Safe Description - The Lab

Team members: Lior Bachar, Yael Blum, Lior Dror, Oded Yuval and Inbar Nachmani.

The Safe’s backstory: The burglars team has participated in the safe tournament but didn’t make it to the final so now they have to take the Physics Lab matriculation. Since they thought they dodged that bullet by participating in the tournament, they did not put effort into actually studying for the matriculation. Therefore, in order to get a good grade, they have to steal the exam’s answers from the lab’s prep-room without getting caught.

General structure of the safe: The safe is designed as a Physics lab prep room. From the outside there is a chalkboard with equations, a whiteboard and a wall of fame with the faces of physicians that changed the world. The safe itself is divided into 2 parts: the first part is completely dark, and the puzzle is based on polarizers. The burglars face 2 perpendicular polarizers, that way no light passes through them. Above the polarizers there is a tiny hole for them to look inside the safe. In order to solve this part they get a smartphone, a ruler and a plastic bag strip. The second part is lit and in this part the burglars see a speaker, a candle and a string with a key tied to its bottom. In order to solve this part they get a smartphone and a lighter (that they get by solving the first part).

The goal: To steal the answers for the Physics Lab matriculation which is about to start in 10 minutes, in order to get a good grade. All of that without getting caught.
The Physics of the safe: All physical principles that the safe is based on, are related to waves: polarizers and light waves, perpendicular polarizers, birefringence and simple optics, sound waves, their frequency and amplitude and how they affect what we hear.

The safe’s puzzles:

In theory, a light polarizer is used as a filter that only lets light with a specific polarization to get through it, and the component of the light in this axis. That is why 2 perpendicular polarizers don’t let any light get through them. So, no light gets to that part of the safe and the burglars can’t see the digits on the inside wall of the safe. When the burglars insert between the 2 perpendicular polarizers a plastic bag, stretch it and rotate it at a 45 degrees angle compared to the polarizers, the light can enter to the safe and they can see the digits. The plastic bag is made of a polymer that achieves birefringent traits when stretched. When the light enters through one polarizer, the bag causes the light to be refracted into two directions so that it has a component that can go through the second polarizer. When the bag is rotated to a 45 degree angle, the light refracts perpendicularly, so the maximum amount of light enters the dark space. In theory, any pulling of the plastic bag in an angle which is not 90/180 degree angle will let a certain amount of light in. however, given the fact that the digits are written in a similar color to the dark background, and the rest of this part of the safe is black, which is a light absorbing color, we need a big amount of light in order to see the digits that are written on the wall, when the bag is pulled in 45 degrees, the birefringence allows the maximum amount of light to get in and the burglars can easily see the digits through the eye hole.

If the plastic bag won’t be stretched, the construction of the molecules of the polymer won’t change, and it won’t refract the light. If the bag won’t be pulled in a 45 degree angle, the amount of light that will enter the safe won’t allow the burglars to see the digits.
In the second puzzle, we focus on sound waves. It requires knowledge in how sound waves travel in the open space—how they are “pushing” air molecules. Waves with high frequencies (short waves) won’t be a big enough interruption that will be able to “bend” the flame of the candle, because they move so fast that a movement of a particle is not enough to influence the flame because it moves back very quickly—there is a movement that cancels it. In this case, we see the flame vibrating in its place. However, low frequency waves are a bigger interruption in the space, because the particles move in a greater distance and manage to move the flame before they “go back”. In addition, the waves must have a big amplitude (loud volume) in order for the interference to move the flame. There is a connection between the wave’s amplitude and its energy, so waves with greater amplitudes push the particles more powerfully. So the sound the burglars need to generate is a loud low voice (big amplitude and low frequency).

the components we used for building the puzzles:

The first puzzle: polarizer, a plastic bag, a ruler, a smartphone.

The second puzzle: a speaker, a candle, a sting, a key, a phone and a lighter.
How to solve the mechanism?

The burglars have a pencil case, with two parts. One of them is locked, and the other one contains a plastic bag, a ruler and a smartphone. The smartphone contains only a flashlight and a voice recorder. In order to solve the first puzzle, they need to insert the plastic bag between the polarizers (the ruler will assist them in this process), and to stretch it at a 45-degree angle. Then, while the plastic bag is still stretched, they need to turn on the phone’s flashlight and to direct it toward the polarizers. The dark part of the safe will be filled with light and the burglars will be able to look through the small hole and see the digits which are written on the wall of the safe, that will open the lock of the second part of the pencil bag. In this part there is a lighter that will help the burglars in the second puzzle. Firstly, they need to
light the candle by pushing the lighter into the hole in front of the candle. Then, they need to record a loud low voice, and press play. The speaker inside the safe will move the flame, which will burn the string and the key for the final prize will fall to a little hole in the floor of the safe, and the burglars will pull it out and open the final prize.

**What Physics knowledge will they need?**

In the first part, the burglars need to use their knowledge in light waves and polarization, and in the second part, their knowledge in sound waves.

**Why only Physics students can solve the puzzles?**

The puzzles aren’t based on trial and error, and they require an understanding in the principals behind them: in the first puzzle the burglars need to understand 2 things: stretching the plastic bag will make it birefringent and in order to let the maximum amount of light to get through the two polarizers, they need to rotate it into a 45 degree angle. The second puzzle requires knowledge in sound waves and their traits-no matter how loud they will shout, sound waves with high frequencies, high pitched voice will not make the flame move and they have to understand that in order to “bend” the flame, they have to record a deep voice (lower frequency) in addition to it’s loud sound.