Report on Weizmann Safe Cracking Competition – The Safeshank Redemption as submission for a Gold Crest Award.

Alex McInerny

Accreditation: https://www.weizmann.org.uk/education/introduction

Video detailing the entire safe, which needed to be submitted for use in judging of the online competition: https://drive.google.com/file/d/15LJ2CdxDXyoNBBybCt8fa09h9gv6-eyP/view?usp=sharing

Foreward:

Not too much to say here – simply, due to the COVID-19 pandemic, the safe cracking tournament wasn't able to be held as it normally should be. Generally, we'd take our safe down to Dulwich school to be judged, and while we were there, we'd try to break into other competitors safes. Due to Government restrictions however, we had to partake in a virtual competition instead, and the international aspect of the competition had to be cancelled due to the rubric not being released early enough, so instead of the competition being international, it was only for competitors within the UK. The format of the virtual competition will be explained later.

The Plan of Action:

The plan is simple; Build a safe – one that is as hard to crack as possible, using only physics principles to make series of puzzles which once solved allow the safe to be opened. Then, to enter our safe into the Weizmann Safe Cracking Competition. The competition is to be judged by a group of panellists, so we shall determine the success of our safe by the competition outcome!

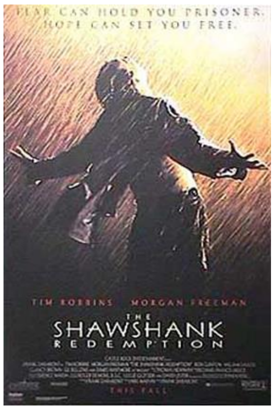
More importantly, however, I wish to develop a series of theoretical and practical skills which will be useful in aspects of my further study – physics at university, and possible future careers whatever that may entail.

The Team:

For the competition, we created a group of five people – all preparing to study STEM related subjects at university. The team includes Alex McInerny (myself), Hashir Majeed, Samuel Caschetto, Velican Kuyumcu and Vanya Artiukhov. The team mascot was Yallah Abdukkah – a yellow duck which we found in our first safecracking meeting. We all had separate roles and specialist skills which we thought would be valuable for the building of our safe, so thought we were pretty well prepared. We got started with the planning aspect of the safe in September 2020.

The Team: from left to right; Hashir Majeed, Vanya Artiukhov, Samuel Caschetto, Velican Kuyumcu, Alex McInerny

The Theme:



Firstly, we have to choose a theme. After much deliberation amongst the team, we've decided to base our safe around The Shawshank Redemption films. We would be using the film as inspiration for the 'plot' of our safe, along with the whole design. The safe shall be built to look like a prison – moreover, the Shawshank prison, however we thought it didn't need to be particularly accurate to the films – something which looked like a prison should suffice. Specifically, the aim of the safe will be for competitors to escape the prison, using a set of hints left by Andy Dufresne, who is one of the main characters from the Shawshank films. Opening the front door will mean that competitors have cracked the safe.

Images depicting my initial plans for the safe, and inspiration from the film 'The Shawshank Redemption'

Initial Designs:

Though only at the starting stages, I already had an idea of what I thought the safe should look like. It has two guard towers at the front, a little wall around the edge, a wardens office along with some cell blocks on the sides. After our first few planning meetings, though I had a general idea of how I wanted the safe to turn out, I thought that it would be best if we got our puzzles in order first. That way, we can design the safe around the puzzles which would be a lot easier than doing it the other way round – after all, the competition is primarily about the physics in your puzzles, not the aesthetics of the safe.

Things the 'crackers' will be given at the start:

- 90% Ethanol Hand Sanitiser (along with other liquids to throw them off)
- Copper pipe with a padlock through it
- First clue – others will be found throught the safe
- Padlocked box containing numerous ball bearings, with only one being magnetic.

1 The First Puzzle: The Relationship Between Pressure and Temperature, along with the high volatility of ethanol.

Right at the start of the puzzle, we plan to give ‘crackers’ a hint. This should be printed out and handed to them, along with all of the items they’ll need to crack the safe. The first clue they’re given will read

> *‘You have been framed for murdering your wife and sent to The Safeshank Prison. Legend has it Andy Dufresne left a hidden plan on how to escape this physics penitentiary. Begin in the boiler room.’*

The competitors will then head to the boiler room and find their next clue. It should hopefully be pretty obvious where this is. This one reads

> *‘Oh good, you’re here. You’ll need to distract the guards here by causing a flash freeze – cooling the thermistor will alert the guards and draw them away from the cell block. Open the box to see Dufresne’s next tactic.’*

Solving the puzzle:

There will be a thermistor connected to an Arduino, which is able to sense the temperature and can freely be moved around within the boiler room. The contestants will need to cool down the thermistor in order for a code to be shows on the LCD of the Arduino. The boiler room will be separate to the rest of the safe, so ‘crackers’ aren’t able to interfere with any other components of the safe while completing puzzle 1.

The principle behind the puzzle is that the alcohol (specifically ethanol – it has a low boiling point and is a VOC (volatile organic compound)) is pressurised, causing almost all of it to condense and become a liquid. The alcohol is then released from the pressure chamber via a valve. The drop in pressure causes the alcohol to vaporise. During vaporisation, the temperature of the alcohol does not change so it needs to absorb the required latent heat of vaporisation from its surroundings. Energy being absorbed from the surroundings in the forms of heat causes a drop in temperature, which in turn will decrease the temperature of the thermistor.

So, all the competitors will need to do is add a volatile liquid to the pressure chamber (they should be given a selection of liquids and need to choose the appropriate one – for example water, ethanol, sugar water etc), attach a bike pump, pressurise it and shake it around a bit, and spray the contents onto the thermistor. Though this sounds easy, they also need to understand the physics behind the system to actually work out what to do.

The Temperature Senser – using a microbit, initial plan:

In order to detect the temperature change, we planned to use a microbit. This would have been very easy to do since it already had a temperature sensor inbuilt into the circuit board. The fact, however, that this was built in was a problem which we hadn’t considered until we had built the final temperature sensor. Since we were using ethanol, which is a pure substance, we believed that there would be no minerals which would connect to contact points on the microbit, and therefore throught it would be fine to combine the ethanol with the microbit, however after testing it, we found that it was not working as it was supposed to be, along with being much less accurate than a normal mercury thermometer, meaning we wouldn't be able to use the microbit. Furthermore, the screen on it isn't actually much of a screen. It's a five by five square of LEDs. This wouldn't have been a major problem, however it's hard to read the code as it moves along the screen since it's such low resolution, so I thought finding another alternative seemed like the best solution.

The Temperature Sensor – using an Arduino, updated plan:

For the updated temperature sensor, we designed an Arduino circuit. It contains a simple potential divider circuit, with a 100k ohm resistor, and a 100k ohm thermistor for maximum sensitivity. As the NTC thermistor is cooled down, the resistance increases. This means that, since it's in a series circuit with the resistor, the voltage across the resistor decreases and the voltage across the thermistor increases. Since an Arduino can't measure resistance directly, it needs to measure the change in voltage. You can use the equation

$$V_{out} = V_{in}\left(\frac{R_2}{R_1+R_2}\right) \tag{1.1}$$

Rearranged to

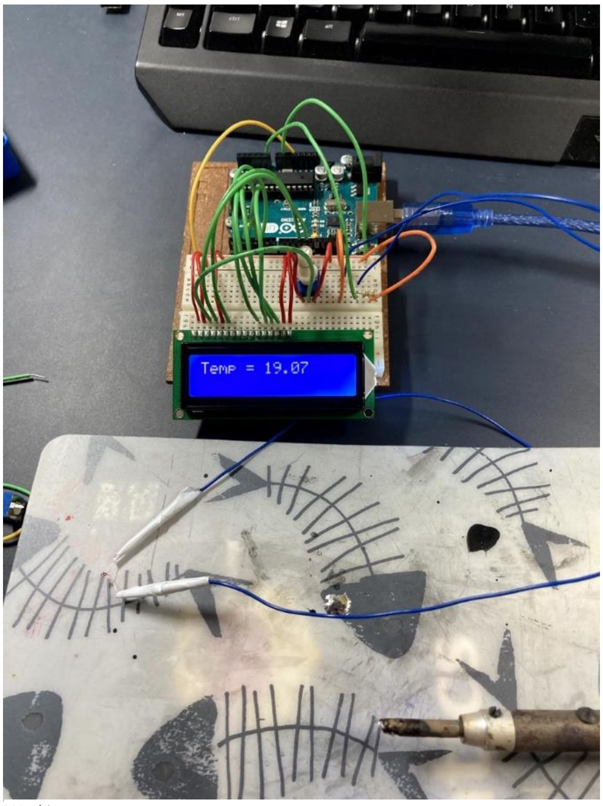
$$R_2 = R_1\left(\frac{V_{in}}{V_{out}} - 1\right) \tag{1.2}$$

Eqn.(1.2) allows us to work out the resistance in the thermistor. Doing this, we can use eqn.(1.3) (the Steinhart-Hart equation) to convert the resistance to a temperature. In order to do this, we needed to calibrate the Steinhart-Hart coefficients such that the temperature displayed will be equivalent to the resistance of the thermistor.

$$\frac{1}{T} = A + B\ln R + C(\ln R)^3 \tag{1.3}$$

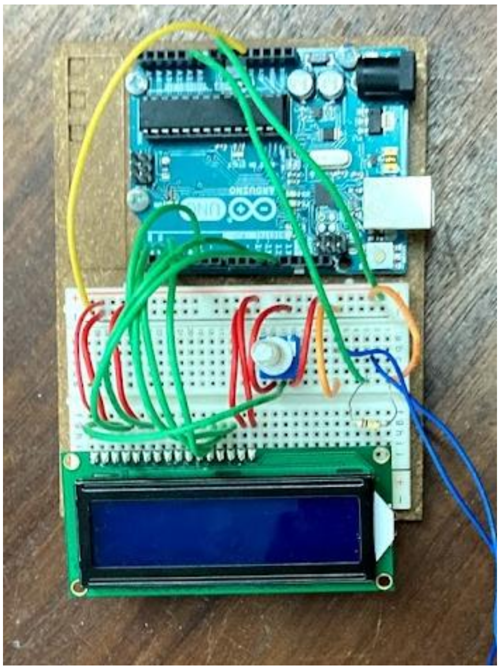
The code we wrote is;

```
#include <LiquidCrystal.h>
  int ThermistorPin = 0;
  int Vo;
  float R1 = 10000;
  float lnR2, R2, Temp;
  LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
  float oldTemp;
  bool puzzleCompleted = false;
  //Steinhart-Hart coefficients
  float  c1 = 0.010155, c2 = -0.00118225, c3 =
0.00000524;

  void setup() {
   Serial.begin(9600);
   oldTemp = CalculateTemperature();
   Temp = oldTemp;
   Serial.print(oldTemp);
  }

  void loop() {
    Temp = CalculateTemperature();
    lcd.print("Temp: ");
    lcd.print(Temp);
    lcd.println(" C     ");
    //CHANGE THE IF STATEMENT FOR -VE TEMP CHANGE
    if (Temp < oldTemp - 8 && Temp > 0){
      lcd.clear();
      Serial.print(Temp);
      lcd.print("Code: 911");
    }
    if(Temp > oldTemp + 3){
      lcd.clear();
      lcd.setCursor(0,0);
      lcd.println("Too Hot");
    }
```



Working temperature sensor

```
    delay(500);
    lcd.clear();
  }

  float CalculateTemperature(){
   //reads v out, in an analog form
   Vo = analogRead(ThermistorPin);
   //Calculates R2 from the potential dividor equation
   R2 = R1 * (1023.0 / (float)Vo - 1.0);
   //Natural logarithm of the voltage
   lnR2 = log(R2);
   //Conversion of R to temp using the Steinhart-Hart equation
(Extension of the B parameter Equation)
   Temp = (1.0 / (c1 + c2*lnR2 + c3*lnR2*lnR2*lnR2));
   //Kelvin to Celcius
   Temp = Temp - 273.15;
   return Temp;
  }
```


Temperature sensor and LCD setup on breadboard

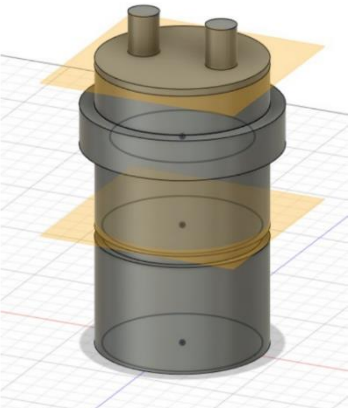
This allowed us to display the code when the temperature of the thermistor was decreased by 8° C. We thought this would be an appropriate change, as you wouldn't be able to do this just by blowing on it etc. Furthermore, we put catches in, meaning if they tried to heat up the thermistor in order to then cool it, it would say that it was too how therefore 'crackers' would have to actually use the pressure chamber in order to complete the puzzle.

When the thermistor has been cooled by the appropriate amount, the code will display on the LCD display, and they will be able to use that code to open the box and move onto the next puzzle.

Manufacturing the puzzle:

It's quite easy to acquire parts for something like this. Using an online PVC shop called Plastic Pipe Shop (and of course amazon), we orderd:

- 1x 2 1/2" Threaded End Cap c/w EPDM Seal
- 1x 75mm-2 1/2" Plain Socket : Male BSP PVC Threaded Adaptor
- 1x 75mm Plain PVC End Cap
- 1x 75mm Short Pipe Piece 250mm long
- 1x 15 PSI pressure relief valve
- 1x bike pump valve
- 1x replacement drop lever valve and a tapping bit.
- 1x PVC cement



The pressure chamber is theoretically pretty simple to build. The idea behind it is a resin casting chamber. We will make it using PVC, PVC cement and epoxy. It shall have a bicycle pump attachment on the side so it can be pressurised without any electrical equipment, can be opened from the top to put in ethanol, will have a safety relief valve such that the pressure isn't increased to dangerous levels, and a small valve such that pressurised ethanol can be sprayed out. My initial design for the pressure chamber looked like this:

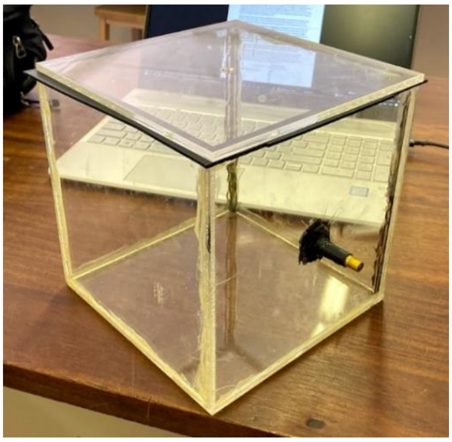
In practice however, the pressure chamber was pretty tricky to make – we needed to ensure that it worked perfectly and reliably. To make it, I cut down the 75mm pipe piece down to 100mm in length using a band saw (courtesy of the DT department). We sanded both of the ends since they were scuffed, and that might have impacted performance. I then put an o-ring on the inside of both of the joints and used PVC cement to stick the end cap on. I did the same thing with the plain socket on the top. The PVC cement then required 24 hours to cure. After that, I used a pillar drill to drill two holes – one from the pump valve and another for the drop lever valve. Both of these holes were slightly smaller than the actual diameter needed. This ensured that there was a tight seal. For the pump valve, we epoxied it in place on the front and back since it didn't have a screw thread on it. As for the drop valve, I needed to tap a hole in the PVC such that the screw thread was able to fit in correctly. I also epoxied the drop valve in, ensuring that there were no gaps for air to escape from.

Testing:

After acquiring all of the parts, and building the pressure chamber, we tested it to great extent in a safe environment (both to ensure it would work when we were demonstrating it and to ensure it was safe to use). We worked out that on average there was a temperature decrease (using a mercury thermometer initially since the temperature senser wasn't yet made) of around 11° C. It was definitely never lower than eight, so we decided to use that as the required temperature change value of the Arduino.

2 The Second Puzzle (which we didn't end up using): The Relationship Between Pressure and Volume.

The idea for this puzzle was to make two boxes out of acrylic, put a pump inside of them and have a lever switch at the top. The switch would be relatively long as shown in the diagram such that it would require little force to be pressed/released. Inside of the boxes there would be two balloons. In one, the balloon would be just smaller than the box, with the switch not being pressed (box 1), and inside of the other the balloon would be ever so slightly larger, where the switch was pressed (box 2).



one of the 'balloon boxs'

The aim on the puzzle would be for competitors would be to pressurise the box containing the larger balloon such that the volume of the balloon decreased, and the switch became unpressed. For the other one, they would need to reverse the check valve inside of the bike pump, such that it now sucked out air. They would use this to decrease the pressure in the box containing the smaller balloon, until it increased inside such that it pressed the switch.

The way the code would be displayed was using a binary lights system. There would be 7 LEDs on the outside of a box (corresponding to a 3 digit code) , some connected to one circuit, some to another and some just there to throw them off. As the switch from the box one was pressed with the balloons increase in volume, it would turn on 2 or 3 LEDs. As the switch from box 2 was toggled, it would turn some of them off. The LEDs which were on would correspond to a binary system of numbers, so competitors would need to convert the binary number into base ten to work out the code for the padlock. Naturally the circuit would not be exposed, so the competitors couldn't work out what the code would be without completing the safe.

Unfortunately, there were numerous problems with this design. Even though the system to get the code was easy enough to make, the manufacture of the boxes themselves was extremely tricky, and the puzzle ended up being extremely temperamental. This is foremost because we designed them as boxes (I designed them on solidworks, then imported them to 2D design and laser cut them from acrylic). There were seemingly always air holes and even if there weren't, the elasticity of the balloons made them extremely hard to inflate/deflate. It was also very tricky to get the gaskets in the correct place, since the boxes needed to be opened by us. Although it might have been possible to make the puzzle work using bell jars instead of cubes, we decided that we would be best off making a new puzzle which was less temperamental.

2 The Actual Second Puzzle: Diffraction and Interference of Monochromatic Light through a Diffraction Grating to work out the Wavelength of a Laser.

From the previous puzzle the 'crackers' should have opened a box which will contain their next clue, along with some other things which they'll use later on to complete the final puzzle.

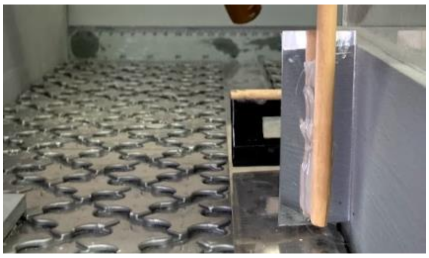
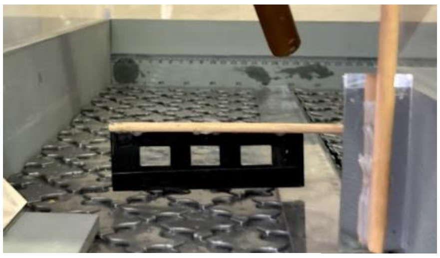
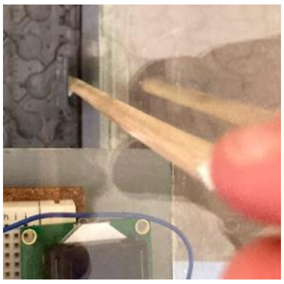
> *'Your absence has been noticed and Warden Norton has put the prison into lockdown. The motion detectors have been turned on with the security cameras on high alert. Direct the lasers into the security cameras in order to blind them and measure the wavelength of light to move onto the next stage. The table and equation to follow may be found useful. Look in the left guard tower for your next clue.*

$$\lambda = \frac{1}{lines\ per\ m} \sin \tan^{-1} \frac{\frac{distance\ of\ two\ outer\ dots}{2}}{distance\ from\ screen\ to\ grating},$$

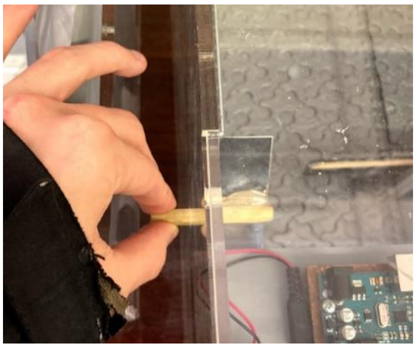
Wavelength (nm) (choose the closest)	***Code***
750	*586*
730	*268*
710	*214*
690	*996*
670	*326*
650	*791*
630	*218*
610	*949*
590	*254*
570	*352*
550	*952*
530	*762*
510	*305*

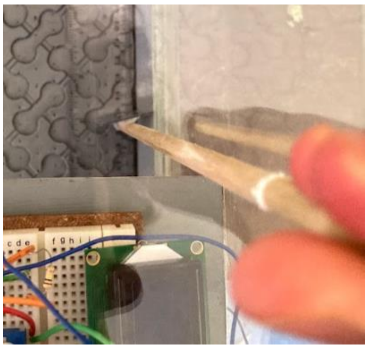
Solving the puzzle:

In order to solve this puzzle, crackers must direct light from one laser, which will be positioned on the oposite wall of a safe, using a series of mirrors through a diffraction grating. They will need to measure the distance from the grating to the screen, and the distance between the two outer dots using rulers which will be positioned within the safe for them. Using this, they can use the formula and table attached with the clue in order to calculate the wavelength and hence work out the code to open the final padlock needed to complete the third puzzle. The crackers must find ways to improve the accuracy of the experiment such that their result is within the $\pm 10\ nm$ provided such as by choosing a diffraction grating with a high number of lines per mm.

Diffraction grating able to move from left to right allowing crackers to choose the # lines per mm





Mirrors being rotated forces crackers to direct the laser into the diffraction grating

Testing:

In order to do initial testing, we collected a 650 nm laser pointer, a diffraction grating and a few meter rulers from the physics classrooms. We set it up, and after many tests, decided that an appropriate distance from the screen to the diffraction grating was around 40 cm. We worked out that with a 600 lines per mm diffraction grating, this would cause a distance of the two outer dots of around 34 cm. This worked relatively well, as the maximum dimensions of the safe allowed for the competition were (600x400x300) mm. Naturally, before attempting to implement this into the safe we tested it many times and worked out that an uncertainty of $\pm 10\ nm$ should be sufficient such that the crackers would get an appropriate result each time. If need be, they could always take multiple measurements and calculate an average. In order to ensure that they got an expected result, instead of asking them to round their answer to the nearest multiple of $(20n - 10)\ nm, n \in \mathbb{N}$, we included a table so they could retrieve the code.

To increase safety, there should be a wall around the edge of the safe, so the diffracted rays from the laser don't go into crackers eyes. Also, the laser used should be less than 5 mW in power.

Diffraction Gratings:

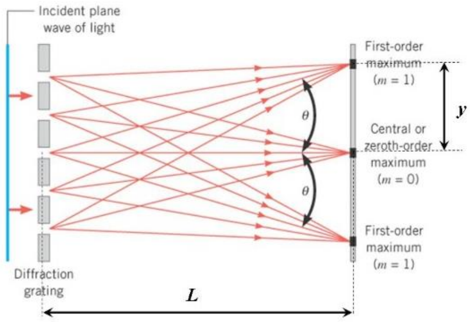


Diagram explaining diffraction gratings

Diffraction gratings are optical elements. They have a structure of many small periodic structures which splits and diffracts light into several beams which all travel in different directions. They do this using interference. Maximums are formed at points of constructive interference, when incident EM waves are in phase – i.e., they have path difference $\Delta x = n\lambda\ m$ or phase difference $\Delta\phi = 2\pi n\ rad$. Minimums are formed at points of destructive interference, when incident EM waves are completely out of phase – i.e., they have path difference $\Delta x = \left(n - \frac{1}{2}\right)\lambda\ m$ or phase difference $\Delta\phi = (2n-1)\pi\ rad$.

The equation for a diffraction grating is:

$$n\lambda = d\sin\theta \tag{2.1}$$

Using eqn.(2.1), you can work out that for a low percentage uncertainty, you want a large ‘distance of two outer dots’ and large ‘distance from screen to grating’, and to get that, you need a large angle theta. Since the sine function is increasing from 0° to 90°, it’s best if you have a small value for d – implying a high number of lines per mm (and by extension lines per m).

Laser Emitting Diodes:

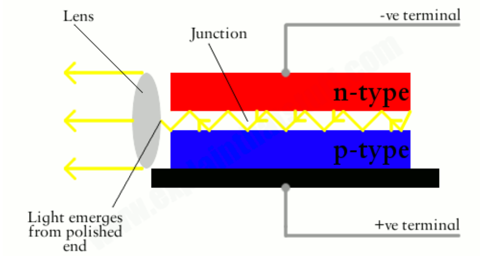


Diagram explaining laser emitting diodes


Laser emitting diode attached to the side of the the safe

An LED is essentially two semiconductors in the shape of a sandwich. The two slices of what would be called ‘bread’ are different materials, called p-type (which is lacking electrons, made of an alloy of aluminium) and n-type (which has slightly too many electrons, made from gallium arsenide). Combining the two, you have a p-n junction diode. Electrons are injected into the diode, and they combine with holes, and some of the excess energy of the electrons is converted into photons, which interact with more incoming electrons, producing more photons etc. this process is self-perpetuating and is known as resonance. The light then emerges through a lens and is highly directional.

Manufacturing the puzzle:


Rulers in place so crackers can measure required distances to calculate wavelength

This puzzle was rather simple in theory, however needed very precise manufacture such that it would work as intended. Firstly, I would need to drill holes in the side of the safe for dowels to be fit in. I ordered some plastic mirrors which I glued onto these dowels so they could easily be turned so the mirrors could direct the laser into the diffraction grating. I glued the grating onto another long dowel and used a cable management clip stuck to the small wall inside of the safe to ensure it would move only in one direction. This small wall, which extended 7 cm above the floor and the entire way around the safe, not only added to the aesthetics of the safe, but prevented the laser light from being shined through Perspex and causing eye damage to someone standing behind the safe. I disassembled a laser pointer and removed the laser diode from it. I soldered this diode to a 3 V battery pack, which is what was in the laser pointer so it had the required current. I glued the laser diode and battery pack to the side of the safe, in position with the mirrors. I also sawed and sanded two rulers to the appropriate size, and glued one to the floor and another to the wall so the required distances could be measured.

3 The Third Puzzle: Lenz's law

The third puzzle we had in mind was a relatively simple one. Generally, the guidelines of the competition state to have two main puzzles to solve and that you're allowed one smaller 'sub-puzzle', to get started or to finish off the safe. In my case, I decided it would be best if we put it at the end.

Puzzle three is modelled off the idea of escaping the prison using the vents.

Solving the puzzle:

Turning mechanism

Wooden rod

Competitors would need to have completed the two other puzzles in order to have got the code for the box (from puzzle one) which contained a series of magnetic/nonmagnetic ball bearings, and a padlocked copper tube (from puzzle two). In order to complete this puzzle, competitors would need to place the copper tube inside of the safe using a hole located in the roof. They'll need to determine which of the ball bearings provided is magnetic and put it into the hole with the tube underneath. Due to Lenz's law (explained later) the ball baring will fall through the tube very slowly. This gives them time to turn the tube through around 180° and allow the ball baring to land on a pivoting balance. When the bearing lands in the hole on the balance, it will cause it to pivot, meaning a cylinder shall be released which will roll out of the safe with the final code writen on it.

Metal Rod used in turning mechanism

Initially, the turning mechanism was made from metal, however after initial testing, we realised that the magnetic ball bearing was attracted to the metal, and wouldn't fall the full way through the pipe, meaning we reverted to the wood one as shown in the diagrams.

Testing:

This puzzle didn't really require much in the testing department – it was more just implementing it into the safe. This is because once we had the copper tube and ball bearing, all we needed to do was drop the ball bearing, realise it travelled slowly and then the concept was confirmed and 'puzzle ready'!

Lenz's law:

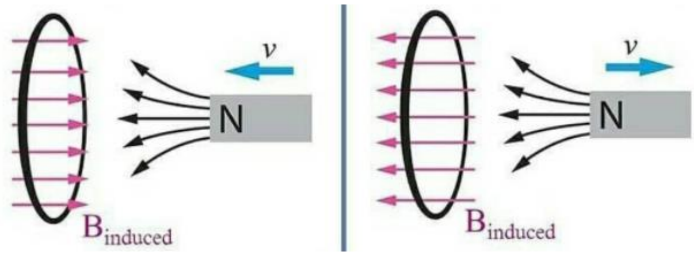


Diagram explaining Lenz's Law

As the magnet falls through the copper pipe, it has a changing magnetic field. This changing magnetic field induces an Eddy current in the copper conductor. The eddy current creates magnetic field in the oposite direction to the magnet one. This opposing magnetic field applies a force on the magnet to slow it down.

The mechanism to give the final code:


Prototype lever balance

The plan was for the bearing to land on a calibrated lever balance, causing it to pivot due to the principle of moments, raising the oposite side and the code being released as it were writen on a cylinder, or just written on the base of the floor or inside of a key which rolled out. Although this was our initial plan, we decided it wasn't particularly elegant and thought we would go for another option.

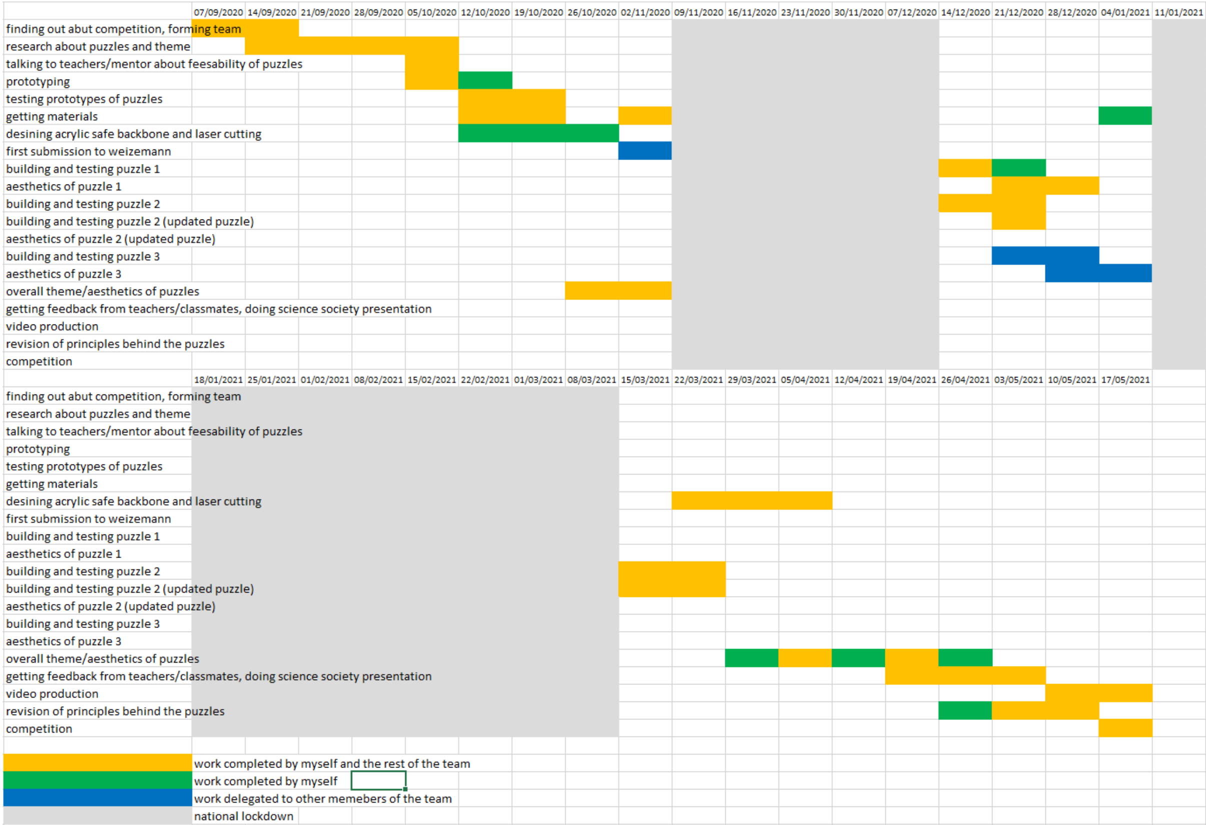
The mechanism to give the final code (updated):


Adapted weighing scale

Updated is a strong word – we devised a totally new way for crackers to get the code. It involved a cheap scale we bought from amazon. The plan was for the ball bearing to fall from the end of the copper tube which crackers had rotated into a scale, whereby the mass would correspond to the code to open the safe. This seemed to work perfectly, in our heads, until our scale arrived, when we noticed the minor oversight of it being magnetic, and the ball bearing being attracted to the scale, causing a wide variation in the apparent weight of the bearing to the scale, meaning the measurement of the mass was very temperamental. To overcome this, I removed the metal plate on the top of the scale and replaced it with a small part which I designed in CAD and 3D printed. The design of the piece was very simple, however very effective. It was a little box, with a floor which pointed only to one direction. That way, the ball bearing would always fall to the exact same place on the balance, causing the same reading to be outputted each time. We tested this extensively of course, and it seemed to work very well. With that, the mechanism to get the final code was complete!

In order to add another level of foolproofness to the safe, we cut a hole in the side of the safe called (for some weird reason), the MOBEEN (when the name was initially developed, it was an acronym but over time we have forgotten what it stood for…). There would be a magnet on the outside of the safe, contained within a plastic box so crackers wouldn't hurt themselves by trapping pieces of skin between two strong magnets. If they missed the scale, all they would need to do was tip the safe to get the ball bearing to the side, use the magnet to raise it up on the wall and pull it over out of the hole in the side of the safe. In this way, we only needed to give crackers one magnet which again greatly reduced the risk of them hurting themselves and encouraged them to think about how to complete the puzzle correctly without wasting time on trial and error.

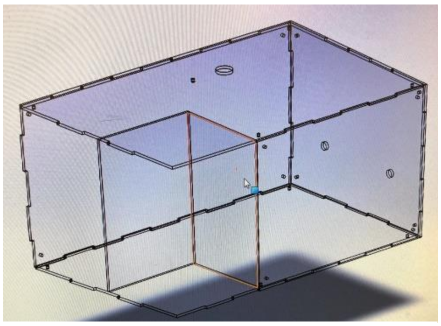
Project Gannt Chart:



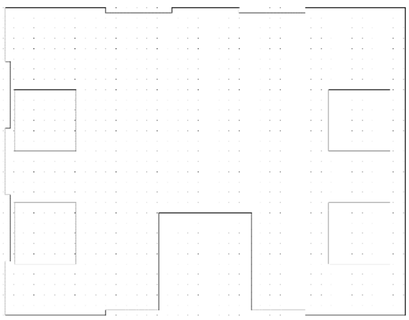
Construction of the SafeShank Prison:

The first step of construction was designing the puzzles – at least the simple idea of them and coming up with the theme of the safe. We did this by looking at previous submissions from students from our and other schools. We searched around on YouTube looking for interesting physics principles which we believed could be adapted into puzzles.

We decided that, once we had what we believed were our final puzzle ideas sorted, making the backbone of the safe was the most important step. Doing this would enable us to fully envisage how everything would sit in the safe. It would also mean that all members of the team understood how everything would 'fit together' in the end, since it's not particularly easy to fully comprehend a plan which is in someone else's head.



Initial design of safe in solidworks, ready to be cut



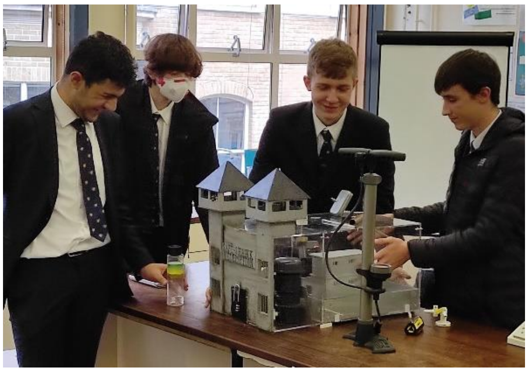
2D design file for front of safe

Initially, I thought it would design the acrylic panels on paper however it seemed like quite a lot of hassle and didn't actually complete the objective mentioned just above, since looking at a series of 2D drawings doesn't give a full picture of how everything would go together. For those reasons, I took to solid works and designed all of the parts in the CAD software. Not only did I think this would be easier to use than 2D design, but it allowed me and the team to look at the safe in 3D, giving us a much better idea of proportions of the safe and how much room we had for the puzzles, allowing us to make progress on them while the safe was being made.

Once the model was made in solidworks, I converted the files into 2D design and was then ready to laser cut them. We went and spoke to the DT department where they taught out how to use a laser cutter safely and offered us help with any other aspects of the safe, which we used later.


The safe just after being assembled

We cut it using 6mm thick clear acrylic (Perspex). This meant that the entire safe would fit perfectly together, and if we needed to add more to it once we had initially cut the side panels, we could put it back into the laser cutter and use it again. This ensured that there was room for change in the design/concepts of the puzzles. We decided on clear acrylic since it would ensure that crackers were able to fully see inside the safe, which would be crucial for solving the puzzles, and allow them the best chance at understanding the principles behind the puzzle. It also ensured that we would easily be able to maintain the safe.


Presenting talk at science society on principles behind our safe

Once we'd made the safe, we worked on implementing the puzzles. Generally, they had already been constructed since we needed to test that they worked before deciding that they were actually the puzzles that we wanted to use. It took a lot of fine tuning to get the puzzles in working order in the safe, and a few minor changes needed to be made. Once all of the physics was in place, we moved onto fully testing and fool proofing them. We also started to focus on the aesthetics of the safe.

For testing, once they were in place and ready to go, we tested each one of them around 10 times. Provided that they each worked every single test, we could be confident that they would work for the virtual competition. When testing, we also cracked them faster than the competitors would to ensure they would withstand the requirement of being able to open the safe withing 2 minutes. Once we had tested them, we got the parallel team to have a look. This meant that we could get unbiased opinions on how the puzzle worked, along with seeing if there were any workarounds to solve the puzzles without understanding the physics which we would need to fix. This information was extremely useful to improve the designs of the puzzles. It also brought forth some errors which we had made such as not being able to retrieve ball bearings if you dropped one in the wrong place.

We also presented a talk for our school science society, running through the design of the safe and foremost the principles of how the puzzles worked. Not only did this allow us to practice presenting our safe, which we would have to do for the judges, but it promoted both safecracking and the uptake of STEM subjects in general!

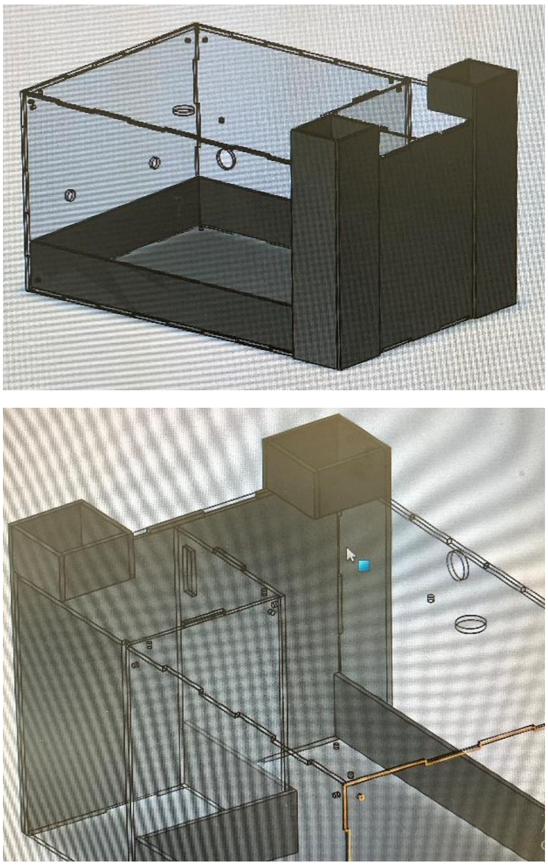
As for the aesthetics of the safe, I had a general plan as to how I wanted the safe to look. I wanted the front to be fully based on a prison, with a large door at the front and two watchtowers on the side. There should be a high wall at the front, and a smaller wall on the side. This smaller wall wasn't only for aesthetics, but it also meant that the laser wouldn't pass through the acrylic as mentioned earlier. So; to solidworks!

Again, I designed the front in solidworks and converted them to 2D design to be laser cut. I did this for the watchtower's towers, however the actual watchtower part I decided would look best, and be far easier to design, if I did it by hand. They were relatively easy to make, since I had a large piece of 3mm ply lying around and all of the appropriate tools at home. I used a circular and jig saw to cut the wood down to the correct size (after having writen up my plans containing dimensions and how it fit together on paper), a multitool to cit out the windows and glued them together, using 6mm squared dowels for supports where necessary.

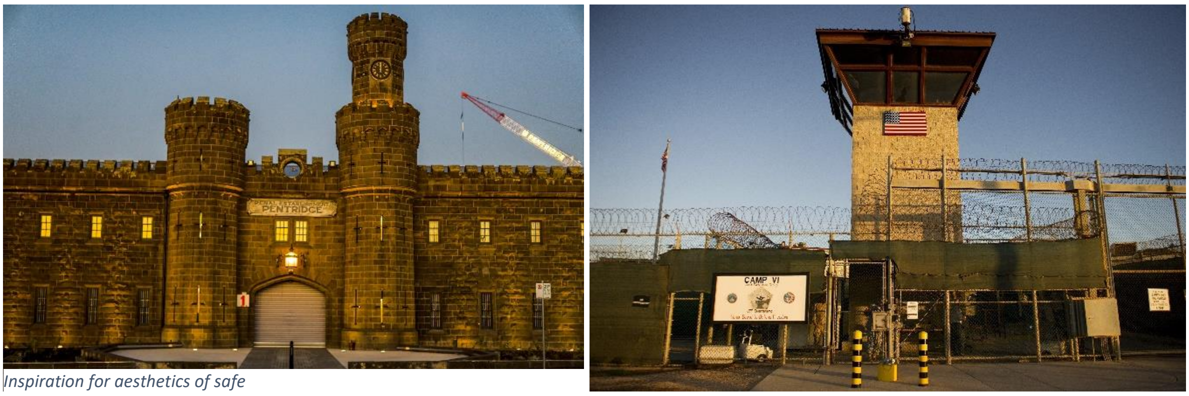
The laser cut pieces were also easy to assemble. Since I'd designed them on CAD, I knew how everything fit together and everything was cut to the perfect size, with very little tolerance. I glued those pieces together with wood glue. Although not shown in the CAD diagrams since they were added later, but I also cut out room for windows, and glued nails onto the inside them to look like bars, along with a front door, which I added a drawbridge gate to. This was the final objective. The last code which the crackers received was the code for the front gate, finally allowing the prisoners to escape.

We also made cells to go inside of the safe, further adding to the aesthetics, and put a floor in the safe. We used some card and square blocks of wood to mount the Arduino and its battery pack next to the designated hole for the thermistor to fit through.

Once everything was assembled, we painted the front and sides grey, and, with some help from the art department, added highlights to the grey paint to make it look far more realistic. We also painted on the name 'The Safe-Shank Prison' on the front, as is shown on the front of most prisons.



CAD designs of the front of the safe, without the watchtowers



Inspiration for aesthetics of safe

So, finally… **The Safe-Shank Prison:**

The (online) Competition and Reflection:

Well… that was fun!

Before the competition, we had to submit a video explaining all of the puzzles in our safe and demonstrating how to crack them. This video can be found here.

Although coming third is a nice bonus, I wouldn't say it's the main thing I (and the rest of the Team) achieved from safe cracking. I learned lots about the processes going into designing and engineering… stuff! I use the word 'stuff' because we had to solve such a wide range of problems, foremost, literally coming up with the problems, but also designing and building the safe, creating and coding the Arduino and much, much more.

Despite encountering lots of problems through the construction of our safe and puzzles, we found ingenuities ways of countering them, and ultimately created a safe which came third nationally in the Weizmann Safe Cracking Competition.

One particularly problem arrived with the Arduino. Initially, it was temperamental at best – sometimes not working at all, and others displaying random signals on the LCD with seemingly no pattern to them.

Despite all of the problems we encountered, I think the skills which I learned when coding and designing the circuitry for the Arduino had very profound real world applications – although they seemed rather simple from the outset (but ended up being exceedingly not-so-simple), I learned a lot about how microcontrollers function – something which is often used in industry along with improving my coding ability.

As for the other puzzles, it's unlikely that anything which comes from a safe cracking competition would have any functional applications solely because you want it to be impossible to break into a safe, so having one which can be opened simply by someone with a little understand of physics would seem counterintuitive. Disregarding this, the aim of the competition is not to build a safe, but more to understand and bring awareness to the physics principles which are so often used in a daily basis.