Physics Extended Essay

Deformation from freefalling – Investigate how the height of drop of molten wax onto a water surface affects its shape and size.

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Abstract

As liquids do not have a fixed shape, liquid droplets are deformed when released from a height onto a surface. The diameter, depth and shape of the deformed droplet is directly related to the drop altitude. In this extended essay, I investigated the change in shape and diameter of molten wax upon dripping onto a water surface and solidifying, comparing and contrasting the differences of the solidified wax formed from different altitudes.

To acquire accurate results, variables in the experiment have been made constant. The same brand of candles was used throughout the experiment to control the density of the wax. The drip outlet of the candle has been controlled to unify the size of the wax droplets.

The analyzed results show several trends with an increasing height of drop. First, the droplets' diameter increased proportionally to the height. Second, the results show 3 different phases to the shape formed by the solidified wax droplets. As the height of drop increases, the shape of the droplets gradually changes from perfectly circular to triangular or pointed, and finally into irregularly shaped splatters.

This phenomenal pointy shape found from the wax droplets is caused due to the increasing impact force upon collision with the water surface. The greater the height of drop, the greater the impact. The forces acting on the edge of the droplet are imbalanced, ending up with pointed edges. When the critical height of drop is reached, splattered wax droplets are formed as the collision of the molten wax droplets on the water changed from perfectly inelastic to partially elastic, causing wax particles to spread outwards.

My extended essay also gave full details on the conclusion and evaluation of the experiment.

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Introduction

As common sense would tell you, a solid object would probably break, or at least deform in its shape when dropped from a great height onto a hard solid surface. This phenomenon happens mainly due to the high impact force generated during the collision, creating a great change in momentum during the impact and thus causing an enormous rupture. Despite having a general impression of how free falling objects drop and end up shattered, not many people actually know about the processes and changes involved behind such a collision.

Take the falling of rainwater droplets as an example. Upon the collision of the rain droplets with the land, it is common to see splashes of water in all directions within a small radius. This is equivalent to the shattering of solid objects. Rain is a liquid, and hence, unlike solids, it has a malleable shape that can be changed with the application of external forces on the droplets. The deformation of an object can also be shown more distinctly for liquid substances than for solids because of this reason. When dripped from different heights, the droplets formed come in various different shapes, sizes and structures. This interesting occurrence has thus incited me to look into the effect of the drop altitude on the change in shape and size of the liquid droplets formed upon this impact.

Since wax does not have a fixed shape during molten state, my experiment made use of molten wax to demonstrate the deformation properties of an object. By observing the solidified shape of the droplets after its collision onto a cold-water surface, we can view a gradual trend on the shape change of the droplets given from various heights. By determining how the shape and diameter of molten wax dripped on a water surface varies with the height of drop, I will also show the deformation properties of a liquid.

Initial experiment design

Before arriving at my final design of the experiment, I intended to use a spherical plasticine lump instead of molten wax as the object of the experiment. A plasticine lump of fixed and known dimensions is dropped into a beaker of water from various heights, while the change in diameter of the lump of plasticine would be recorded. By observing the different diameter changes of the plasticine lump when dropped from various heights, I hoped to find a gradual relationship between the height of drop and the deformation that the water surface produced on the plasticine lump.

The variables in the experiment were controlled and investigated in various ways. First, the height of drop of the lump was assigned as the independent variable, while the diameter of the lump was assigned as the dependent variable. Other variables such as the initial shape and the density of the plasticine lump used are fixed and kept constant.

The height of drop started off at 3 cm above water surface, and 10 suitable sets of the lump diameter data was collected for each height. The experiment was repeated with an increase of 1 cm in the height of drop each time, until sufficient data was acquired.

Many flaws were present in the initial design. First, I falsely believed that the lump of plasticine was flexible and malleable enough to show distinct deformation upon collision with the water surface. Although plasticine can be moulded into different shapes, the applied force required to change its shape was too great, and the minor reaction force of the water surface acting on the lump was too insignificant to show distinct deformation.

Secondly, the density of the plasticine lump is a lot higher than that of water. Therefore, the lump of plasticine, even though having a relatively small mass, would sink for a certain depth before it rebounded. The upward buoyancy resisting the downward sinking force would indefinitely contribute more or less to the deformation of the plasticine's shape, adding a source of error to the experiment by enlarging the actual diameter change of the spherical plasticine lump.

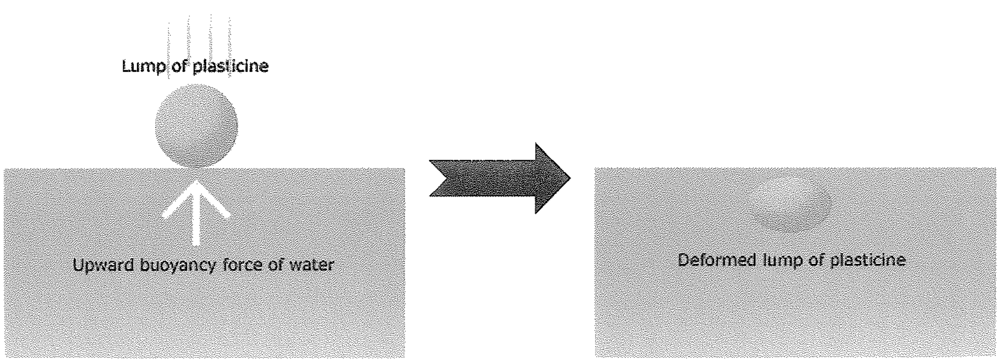

Figure one: Initial model of the experiment using a plasticine lump

Modified experiment design

After further revision of the experiment method, a better approach was developed to tackle the investigation question. Instead of measuring the change in the diameter of the plasticine lump upon impact with the water surface, dripping molten wax into the beaker of water was found out to be a more effective alternative to investigate the drop altitude to size relationship. This experimental modification not only solved most of the technical problems that were encountered previously, but also improved the experiment in many ways.

The variables in the experiment using the new method remained more or less the same. The dripping height of wax was assigned as the independent variable, and was increased unitarily to observe a gradual change in the dependant variable – the shape and diameter of the wax droplets formed. On the other hand, the controlled variables included the density of the candles' wax, the shape of the drip outlet of the candlestick, and the impact time of the collision. The methods of maintaining the controlled variables will be discussed further onwards in the paper.

The molten wax is dripped from the candle tip into the pool of water, where it immediately cools down and solidifies upon contact with the cool water surface. The immediate shape of the wax droplets upon collision is hence captured, and can be clipped off the water surface with care to measure the dimensions of the droplets. With a greater height of drop, the diameter and depth of the molten wax would theoretically be larger. By approaching the problem with this new method, both the quality and efficiency of acquiring the data, as well as the accuracy of the experiment were greatly improved.

First of all, unlike dropping a plasticine lump, which must be re-obtained and remoulded to its initial shape before the collection of the next data sample for that height, wax dripping can occur continuously, collecting all data required for that height of drop in the same conditions and minimizing unnecessary movement or alterations of the system environment.

Secondly, since wax in molten state has a significantly lower density than plasticine, the molten wax shows more observable change in its size with different heights of drop than plasticine does. As the wax droplets float on water due to the low density, they will not be affected by the minor deformation caused by the buoyancy force when the plasticine lump sinks to the bottom of the beaker of water.

Moreover, as the wax droplets have a comparatively smaller size to the lump of plasticine, the droplets can be collected and stored for further use or for reference.

Preliminary Observations

My initial hypothesis was that the wax droplets would show a gradual increase in the diameter as the height of drop increased, and that with a change in height, the wax droplets would be deformed into different shapes and sizes.

At first, the wax droplets were all expected to be circular in shape until the critical drop altitude was reached, where the wax formed would then start to appear in a splattered shape. Yet contrarily to my expectations, the droplets appeared in not only two shapes, circular and splattered, but also in a pointed shape.

When dripped from a low height, perfectly circular droplets were observed as expected, and above the critical height, the wax formed were splattered. But between the two stages, pointed droplets were formed as an intermediate phase. As the height of drop increased, the number of pointed edges gradually increased from none (perfectly circular) to two, three, four or up to five pointed edges. At first, I had no idea why pointed edges were formed in the droplets, and thus found this to be quite a fascinating phenomenon. Hence, I decided to go into further detail the reasons behind the formation of these pointed edges and to find the relation of the formation of these pointed edges with the height of drop of collision as well.

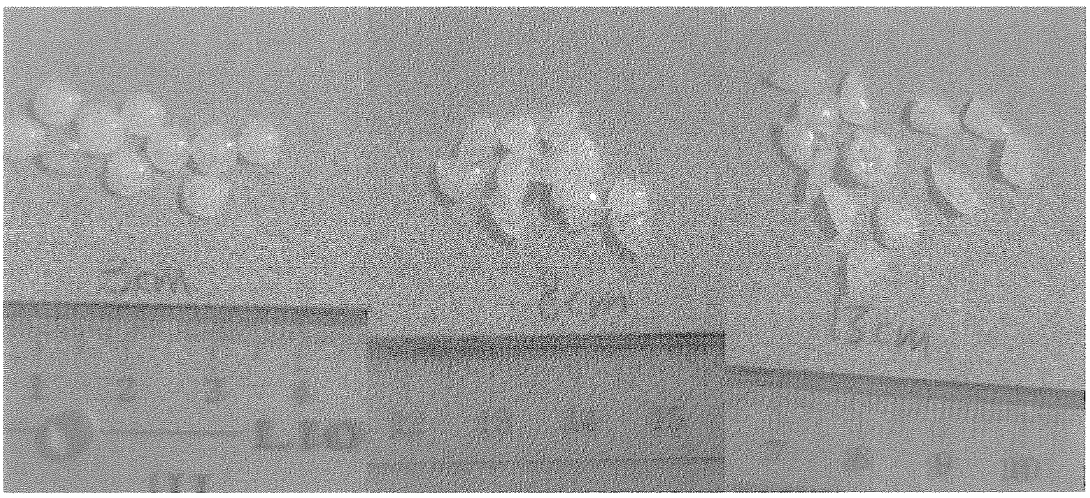

Figure two: Observations of wax samples from different heights

Experimental procedures

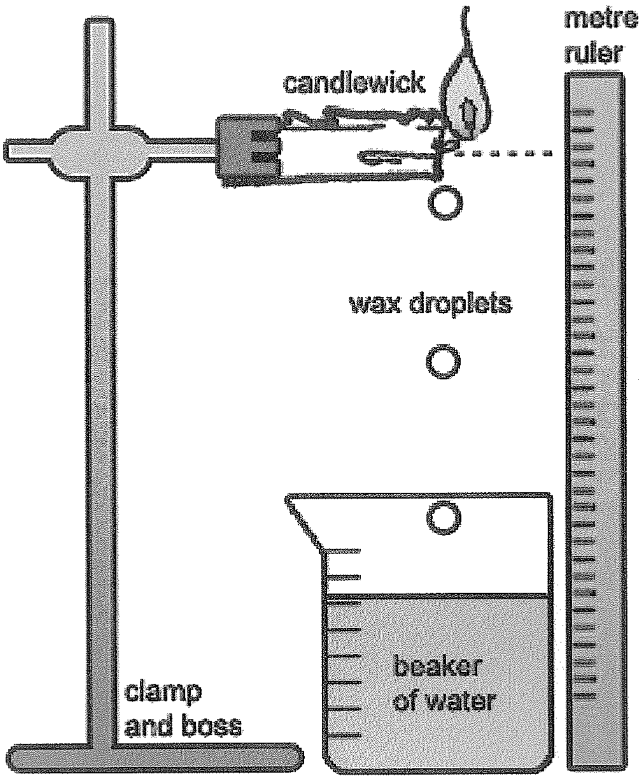

Figure three: Setup of the experiment

List of apparatus

- "Bright Candle" brand candles made in China.
- Empty Beakers
- Water
- Clamp and boss
- Lighter
- Vernier callipers
- Meter ruler
- Clippers

First of all, the equipment is set up in place as shown in figure 3. A beaker is filled with sufficient water (approximately 10cm deep). The candlestick is attached onto the clamp and boss so that the candlewick is directly above the centre of the beaker of water. A meter ruler is fixed to the side of the set up for determination of the height of drop. The height of the clamp is adjusted, so that the flick of the candlewick would be at the desired drop altitude.

The position of the water level and the central position of the candlewick respective to the meter ruler are recorded down to calculate the drop altitude. The candle is then lighted, after which wax droplets will regularly drip into the pool of water. Upon submerging, the wax droplets' kinetic energy will be converted into potential energy as it sinks down the water, while a portion of that kinetic energy will be carried and dissipated outwards by the water ripples formed. The force of the water waves would most likely act outwards and drive the droplets further away from the centre of the circular water surface, emptying the central space of the beaker for the next droplets. Occasionally, if the droplets in the centre are not washed aside in time, the next droplet would land on top of another wax droplet, causing overlapping of the wax samples. This data sample would hence be omitted, as it cannot accurately represent the actual diameter and depth of wax droplets formed from that height.

When sufficient viable wax samples are produced, the samples are gently clipped from the water surface onto a dry piece of paper towel without damaging them. The splattered samples are especially fragile because for the same mass of wax, the wax spreads over a larger surface area, having a thinner thickness. These samples must then be handled with extreme care, as they are more easily shattered when the delicate edges of these splatters are clipped off the water surface.

For each height of drop, about 10 to 15 data samples are collected. The mean diameter of the 10 wax samples will then be calculated to obtain the average droplet diameter for each height of drop, which gives us a more accurate representation of the actual size of wax droplets created. As the samples collected only have a diameter ranging from about 5 to 15 mm, a Vernier Calliper is used to precisely measure its diameter. In addition to collecting values of the diameters of the droplets, observations of the size, shape, colour and texture of the wax droplets are also recorded down.

After the collection of each set of data, the length of the clamp arm should be lengthened and re-orientated appropriately because the candle would become shorter in length as it is being burnt. The lengthening of the clamp arm can then therefore return the centre of the candlestick to its original position and re-initialise the experiment set-up to prepare for the collection of the next set of data.

The above steps are then repeated with an adjustment of height each time, usually by raising the candle height by 1 cm. The experiment is continued until a spectrum of data has been collected.

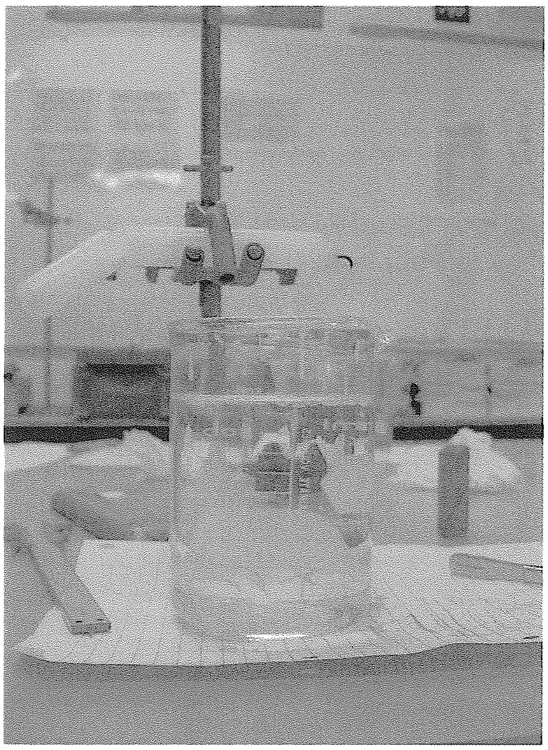

Figure four: Photo of the experiment setup

Controlling of variables

A greater impact force will cause greater deformation on the wax drops. Since the momentum change is fixed, the impact time can be extended by compressing and deforming the wax to cope with the impulse. The following variables must thus be controlled to kept constant the impact force.

1. **Density of the wax**

$$F=ma$$
$$\rho=m/v$$
$$F=\rho va$$

The impact of the collision of the wax upon the water surface is directly proportional to the mass of wax droplets as dripped wax with a larger mass will strike the water surface with a stronger force. Also, since the mass of the droplets is directly proportional to its density, hence a variation in wax density would change the force of impact of the collision. This would thus lead to differences in the final thickness and diameter of the droplets formed.

In our experiment though, we accept the assumption that the density of wax is the same for each candlestick, hence by using the same brand of candlesticks throughout the experiment, the wax density is indirectly controlled.

2. **Shape of drip outlet (Volume of the droplets)**

Since the candle tip is circular in shape and is not a single point, wax dripped from the top or bottom part of the candle will correspond to different height of drops. Also, as mentioned in the above criterion, the final dimensions of the droplets are directly proportional to its mass. When the wax density is constant, droplets must have the same volume in order to have the same mass. The controlling of both the volume of wax droplets and the height of drop eventually involves the controlling of the drip outlet.

To control the drip outlet, before starting to use each new candlestick, the candle itself is left lit sideways for a short period of time. This will leave the candlestick with a pointed tip on one end because the flame of the candlewick always burns upwards, hence the upper part of the candle will be consumed a lot faster than the lower part. When the wax of the candle becomes molten, it will follow the curve of the candle top to the pointed edge and drip off the pointed candle tip.

As a drip outlet with different shapes and sizes will produce wax droplets of different sizes, the shape of the drip outlet will determine the wax droplets' initial volume. By using the pointed drip outlet, we are indirectly controlling the size of the droplets to be at a constant mass.

Another reason why a drip outlet is needed is to set up the standards for measuring the height of drop. Without the drip outlet, it would be uncertain whether to determine the position of dripping as the top of the candle, the centre part of the candle or the bottom of the candle. When the drip outlet is set, it would be obvious to take the bottom part of the candle as the appropriate point of drop for measurement purposes.

3. Determination of diameter of irregular shaped droplets

For perfectly circular shaped droplets, comparisons are made between the diameters of the wax droplets to observe a progressive trend in the size of the droplets. But as the height of drop increases, pointed edges are formed in the droplets, and instead of the diameter, the longest possible distance between the sides of the wax droplets are measured instead.

As for splattered wax, the shapes are completely random and chaotic due to the incalculable formation of the splatters. There is not a suitable scale for measuring the amplitude of the deformation due to limitations of measuring methods. Hence splattered wax samples will only be left for analysis on the formation of its shape, but will be omitted when used to investigate relations between size of the wax formations and the height of drop.

Primary data collected

Height of drop (*h*)/cm	3.0	4.0	5.0	6.0	7.0
Droplet diameter (*d*)/mm	5.40	5.60	6.10	6.30	6.80
	5.40	5.60	6.10	6.30	6.80
	5.45	5.55	6.00	6.00	6.85
	5.40	5.85	5.90	5.90	6.35
	5.10	5.55	5.90	5.90	6.35
	5.20	5.70	6.30	6.80	7.00
	5.20	5.70	5.90	6.70	6.45
	5.10	5.90	6.00	6.20	6.55
	5.10	5.55	5.90	6.50	6.55
	5.10	5.60	6.10	6.20	6.60
Standard deviation (*S.D.*)	0.15	0.13	0.13	0.31	0.22
Average diameter (d_{ave})/ mm	5.245	5.660	6.020	6.280	6.630
Uncertainty of diameter (δd)	0.047	0.040	0.042	0.099	0.070
% uncertainty (δ%)	0.90%	0.71%	0.69%	1.57%	1.06%

Height of drop (*h*)/cm	8.0	9.0	10.0	15.0	20.0
Droplet diameter (*d*)/mm	7.15	7.40	7.90	14.10	8.20
	7.10	7.15	7.10	7.80	13.50
	7.25	7.00	7.20	8.60	9.75
	6.55	7.20	7.20	9.00	7.90
	7.05	7.00	8.00	8.10	9.90
	7.55	7.30	8.00	14.85	12.60
	7.40	7.25	7.55	10.25	8.90
	7.40	7.25	7.00	9.00	8.80
	7.35	7.75	7.80	7.70	9.00
	7.00	7.10	6.90	8.65	7.20
Standard deviation (*S.D.*)	0.28	0.22	0.43	2.57	2.01
Average diameter (d_{ave})/ mm	7.180	7.240	7.465	9.805	9.575
Uncertainty of diameter (δd)	0.090	0.069	0.137	0.813	0.636
% uncertainty (δ%)	1.25%	0.96%	1.84%	8.30%	6.64%

Table one: Data collection of droplet diameter at different heights of drop

Height of drop (*h*)/cm	Observations on shape of droplets:	Surface texture
3.0	Circular biconcave droplets	Smooth
4.0	Circular biconcave droplets	Smooth
5.0	Pointed droplets with 2-3 pointed sides	Smooth
6.0	Pointed droplets with 3-4 pointed sides	Smooth
7.0	Pointed droplets with 3-4 pointed sides	Rugged
8.0	Pointed droplets with 3-4 pointed sides	Rugged
9.0	Pointed droplets with 3-5 pointed sides	Rugged
10.0	Pointed droplets with 3-5 pointed sides	Rugged
15.0	Squished irregular shaped splatters	Splattered
20.0	Squished irregular shaped splatters	Splattered

Table two: The shape and surface textures of droplets formed at different drop altitudes

Calculation of data:

- The average diameter (d_{ave}) is calculated by adding up all the droplet diameter (d) measurements and then dividing the summed up value by the total number of data collected (N).

$$d_{ave} = \frac{\sum d}{N}$$

- The standard deviation (S.D.) is a measure of the degree of deviation of the data samples from the mean value of the data. It is calculated using the standard deviation function in a spreadsheet program.

- The uncertainty of the average diameter (δd_{ave}) is found by dividing the standard deviation of the diameter data (S.D.) of the droplet diameter measurements with the square root of the number of trials ($\sqrt{N}$).

$$\delta d_{ave} = \frac{S.D.}{\sqrt{N}}$$

- The percentage uncertainty ($\delta\%$)of the value is found by dividing the average diameter with the uncertainty of the diameter (δd_{ave}).

$$\delta\% = \frac{d_{ave}}{\delta d_{ave}}$$

Analysis of data:

As seen from the primary collected data shown below, wax droplets formed from the heights of 15cm and 20cm are all splattered wax. They are obtained with a precision uncertainty of 6.64% & 8.30%, and have a standard deviation of up to 2.57 & 2.01 respectively. Therefore these sets of data can be considered as irrational and are not taken into account for calculation.

By analysing all the recorded data above, we can come up with the table below:

Height of drop	Diameter of wax droplets	x -ve error bar	x +ve error bar	y -ve error bar	y +ve error bar
3	5.245	0.1	0.1	0.90%	0.90%
4	5.660	0.1	0.1	0.71%	0.71%
5	6.020	0.1	0.1	0.69%	0.69%
6	6.280	0.1	0.1	1.57%	1.57%
7	6.630	0.1	0.1	1.06%	1.06%
8	7.180	0.1	0.1	1.25%	1.25%
9	7.240	0.1	0.1	0.96%	0.96%
10	7.465	0.1	0.1	1.84%	1.84%

Table three: The average diameter of wax droplets for each drop altitude

After inputting the tabulated data into a spreadsheet program, a linear graph showing the relationship between height of drop and diameter of the wax droplets is obtained.

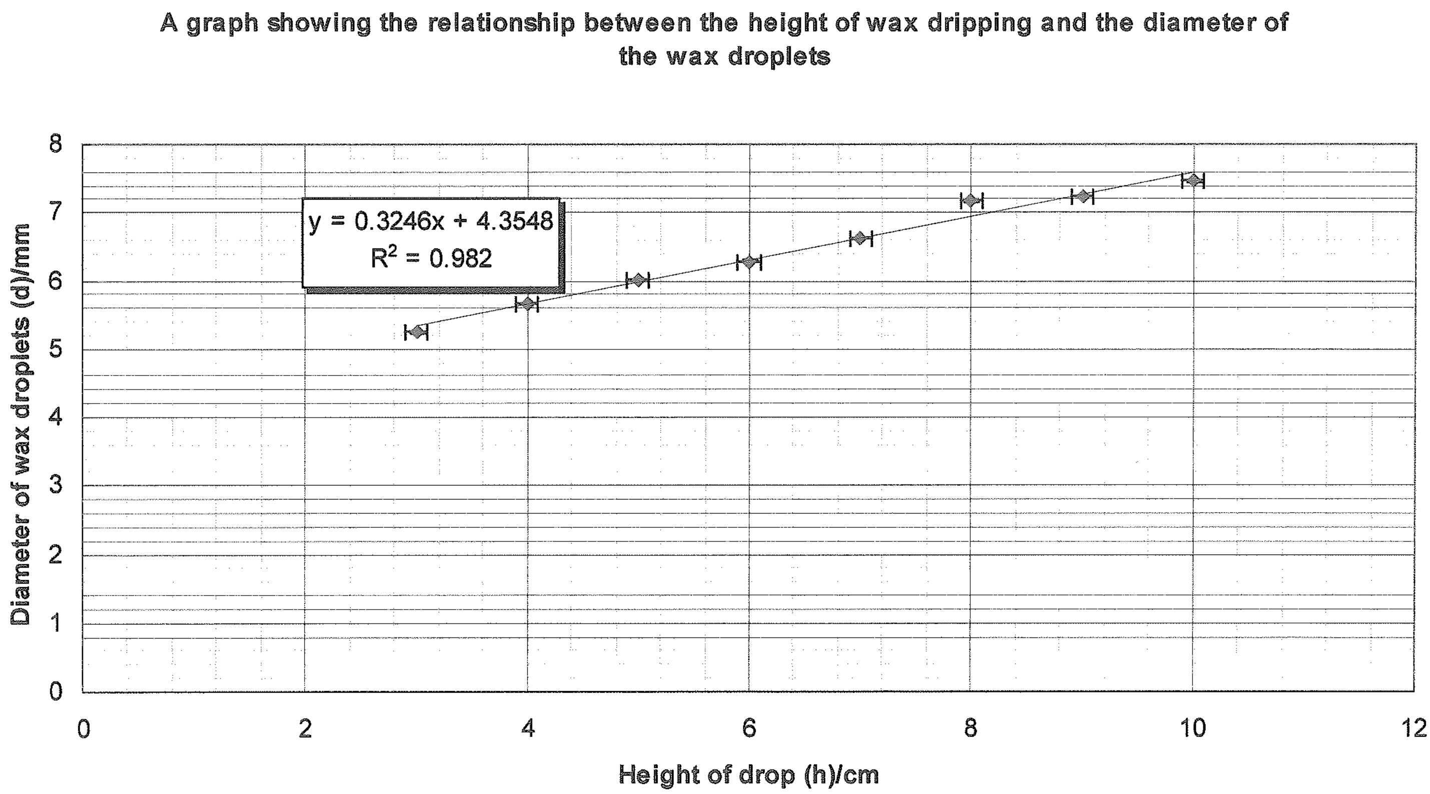

Figure five: A graph of drop altitude against wax diameter plotted using data from table three

Analysis of the shape of wax droplets:

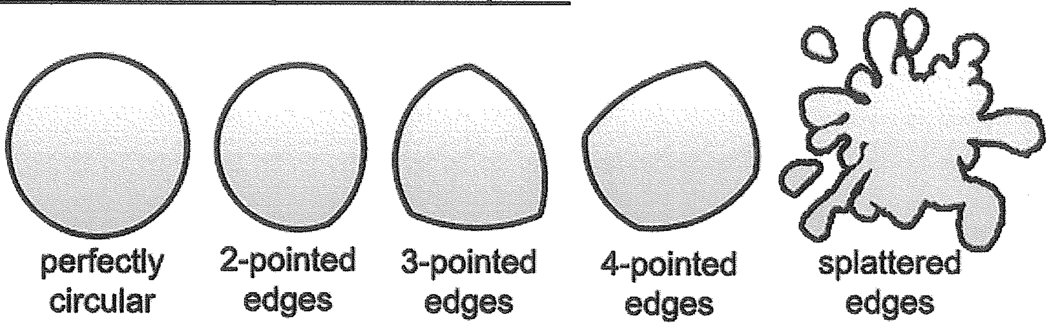

Figure six: Diagrams of the different shapes of the droplets formed

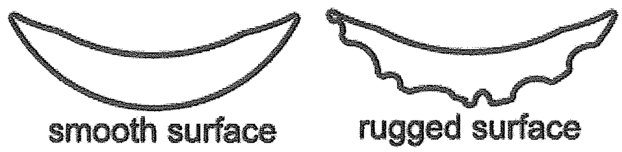

Figure seven: Diagrams of the different surface textures of the droplets formed

As shown from Table 2, the shape of the resultant droplets varies with the height of drop. When the wax is dripped from a relatively higher altitude, more edges are found and the surface texture of the wax droplets gradually becomes rugged.

Why pointed edges are formed on the wax droplets at higher drop altitudes:

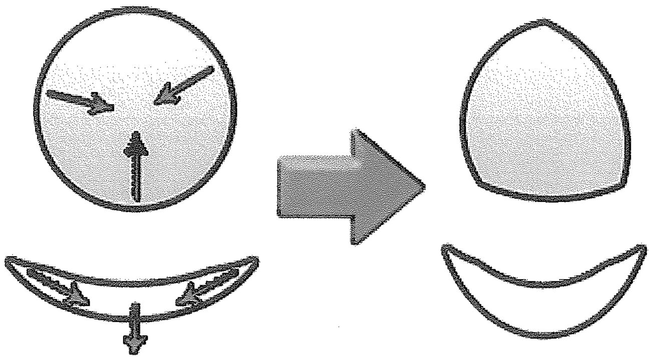

Figure eight: A diagram showing how the forces acting on the droplet deform its shape

With a greater height of drop, the velocity upon impact with the water surface would also be greater. The depth of the wax droplets reached underwater reflects the distance required for the upward buoyancy force of water to completely dissipate the kinetic energy during the collision.

For lower heights of drop, the depth reached is low, and hence the downward pulling force acting on the centre of the wax droplets because of this is relatively small. As the volume of wax is fixed, the sides of the wax droplets are hence pulled towards the centre of the droplets, but only slightly, resulting with a circular shapes droplet. As the height of drop is raised, the downward pulling force would also increase steadily. The force acting on the edges of the wax droplets would gradually increase from none to two, three, four or five resultant forces acting on the central position of the droplets, pulling the sides closer together and leading to the formation of pointed edges.

Figure nine: A photo showing samples of pointed wax droplets

Why rugged surfaces are formed on the wax droplets at higher drop altitudes:

With a fixed volume of wax, the droplets must displace the wax particles from the depth of the droplets to the edges of the wax droplets during compression in order to extend the impact time. When simply compressing the wax droplets can buy not enough time, some of the wax will be displaced from the originally smooth and curved wax surface to its edge, hence the wax texture becomes rugged with a concave surface.

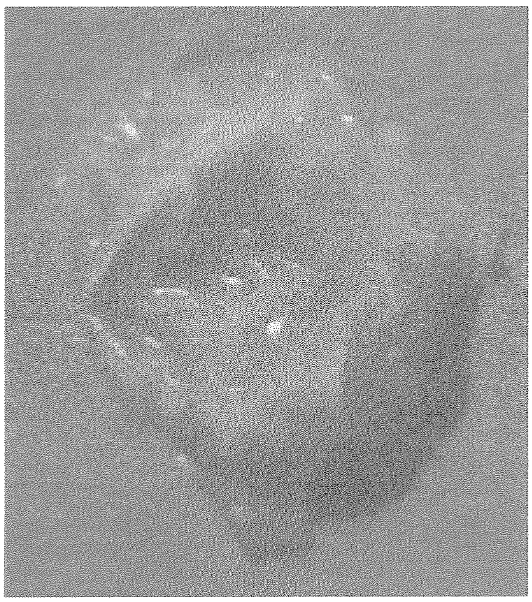

Figure ten: A photo showing a sample of a splattered wax droplet

Why splatters are formed at higher height of drops:

When the critical height is reached, splattered wax samples start to form. This is because the impact velocity has reached a certain level that the collision between the water surface and the wax droplets has become partially elastic instead of perfectly inelastic. The wax particles are rebounded off the water surface upon collision and are spread outwards. With a greater height of drop above the critical height, the wax particles are spread further and the splatters are larger in size.

Conclusion:

The formula for the graph in figure 5 is given to be:

$$y = 0.3246x + 4.3548$$

As verified from the graph, the diameter of the wax droplets formed is directly proportional to the height from which it was dripped. For each increment of 1cm in the height of drop, the diameter of the wax droplets will be increased by approximately 0.33 mm. This completely matched my hypothesis that the change in diameter of the wax droplets would be directly proportional to the height of drop. By extrapolating the line to cut the y-axis, we could see that the theoretical diameter of wax droplets formed, if they were dripped from the water surface, would be approximately 4.3 – 4.4 mm in diameter.

By the law of conservation of energy, the gravitational potential energy (E_p) of the wax droplets at the height of drop is equal to the kinetic energy (E_k) of the wax droplets during its collision with the water surface. Hence, we can see that the height of drop (h) is proportional to the square of the impact velocity (v^2) during the collision.

$$E_p = E_k$$
$$mgh = \tfrac{1}{2}mv^2$$
$$v^2 = 2gh$$

By Newton's second law of motion, it is shown that the impact force (F) is directly affected depending on the change in momentum (ΔP) during the collision. In the experiment, the mass of wax droplets (m) is a controlled variable as explained previously, and is assumed to be constant throughout the experiment. By controlling the mass and volume of wax droplets (v), the impact force is also controlled. The gravity on earth (g) also has a constant value of $9.86 ms^{-2}$, therefore we can combine these variables into a constant value C for convenience. As a result, having a constant impact force, the height of drop is directly related to the square of the impact time

$$Ft = \Delta P$$
$$Ft = mv - mu$$
$$Ft = mv - 0$$
$$Ft = m\sqrt{(2gh)}$$
$$C_1 = \frac{h}{t^2}$$

In order to compromise for the increased change in momentum when the height of drop is increased, the impact time must be subsequently increased as well. As the square of the impact time is directly proportional to the change in the thickness of the wax droplets (Δw), and the change in thickness of the wax droplets is also directly proportional to the change in the radius of the wax droplets (Δr) formed, hence the height of drop is directly related to the increase in diameter of wax droplets.

$$t^2 = k_1 \Delta w$$
$$\Delta w = k_2 \Delta r$$
$$t^2 = k_3 \Delta r$$
$$C_1 = \frac{h}{k_3 \Delta r}$$
$$C_1 = \frac{h}{\Delta r}$$

Evaluation:

The results obtained in the experiment are quite accurate, as the average diameter of the wax droplets of different drop altitudes are all aligned on the same line as shown in figure 5. Since the results are both accurate and precise with a maximum uncertainty of only ±1.84% in the data, the maximum and minimum line of best fit deviates from the best-fit line by very slightly.

Errors in the experiment:

- The molten wax was dripped from the candle tip, which had a strong attractive force on the molten wax drip, giving the wax drops an initial tear-dropped shape instead of a spherical bead shape. This systematic error created initially elongated droplets, which contributed to an increase in impact time. The problem is systematically impossible to improve with our limited laboratory apparatus since the molten wax solidifies too quickly to be able to be manipulated effectively to solve this problem.

- Despite my attempt to determine the size of a pointed droplet as the greatest distance between two of the points on the droplet, this is an inaccurate measurement since the random shape of droplets range from rice-shaped to diamond-shaped samples. This is a random error that must be taken, and can only be adjusted by taking a larger sample of readings for the same height to get an accurate mean value.

- Although we have already controlled the tip of the candle so that the molten wax would drip at the outlet with a constant shape and volume, but this is based on the assumption that the shape of the tip of the candle will no longer change. This is in fact an invalid assumption as the heat of the candle will still melt the candle tip by more or by less, and the slight variation in the shape of the tip will enlarge or diminish the volume of the molten wax, causing a non - constant mass of wax dripped.

Acknowledgement

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- Our school lab technician. He helped me on the preparation and setting up of the experiment equipment.

Bibliography

- ***Six roads from Newton – Great discoveries in physics***
  Edward Speyer (John Wiley and sons, inc)
- ***The shape of raindrops***
  http://www.eng.vt.edu/fluids/msc/my_pages/raindrops/raindrop.htm
- ***Simulation of Bubble motion under Gravity***
  http://wwwsoc.nii.ac.jp/aesj/publication/JNST2001/No.5/JNST_330-341.pdf
- ***The man who defies gravity***
  http://www.cwru.edu/pubs/cwrumag/spring2001/features/defiesgravity/cont1.shtml
- http://www.ucy.ac.cy/~georgios/pdfiles/ijnmf00.pdf

Appendix

Photos taken for the sample data collected from various heights of drop:

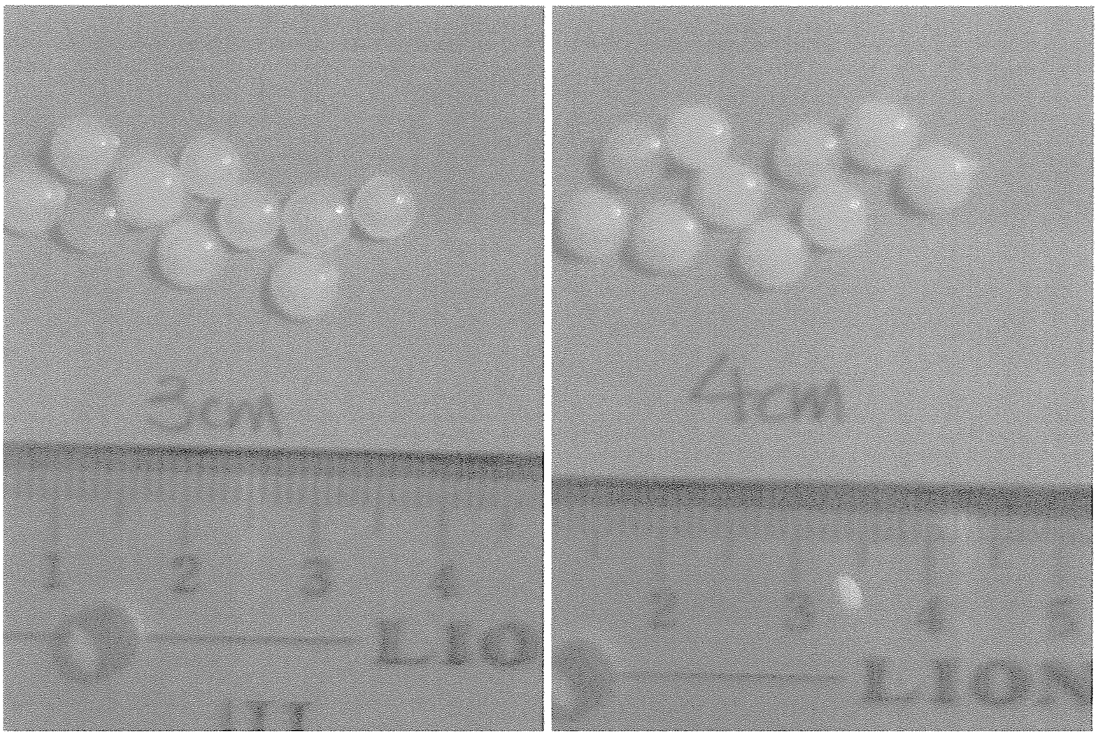

Figure eleven (a),(b): A photo of wax droplets formed from wax dripped from 3cm and 4cm.

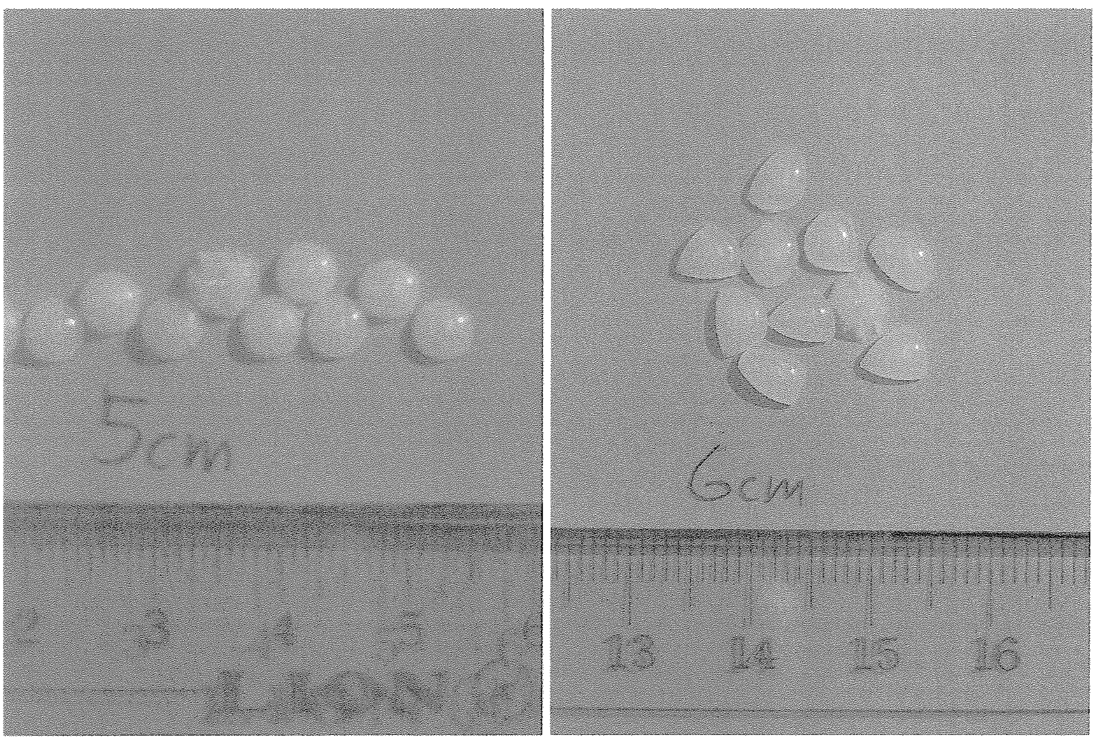

Figure eleven (c),(d): A photo of wax droplets formed from wax dripped from 5cm and 6cm.

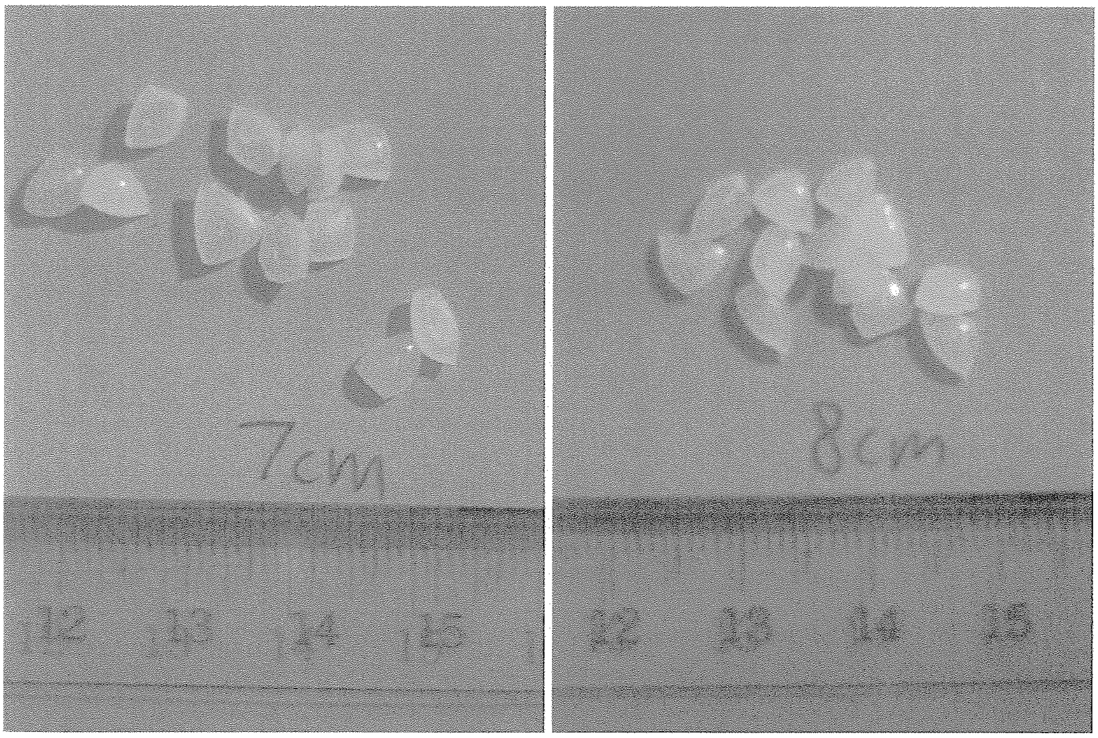

Figure eleven (e),(f): A photo of wax droplets formed from wax dripped from 7cm and 8cm.

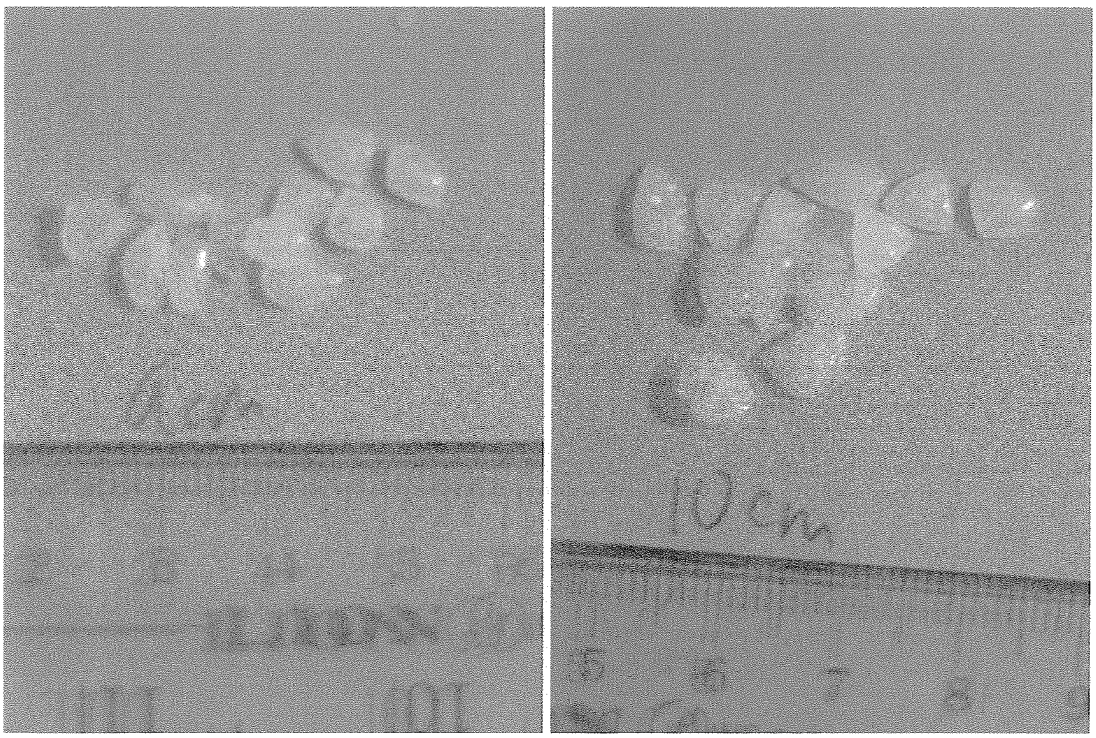

Figure eleven (g),(h): A photo of wax droplets formed from wax dripped from 9cm and 10cm.

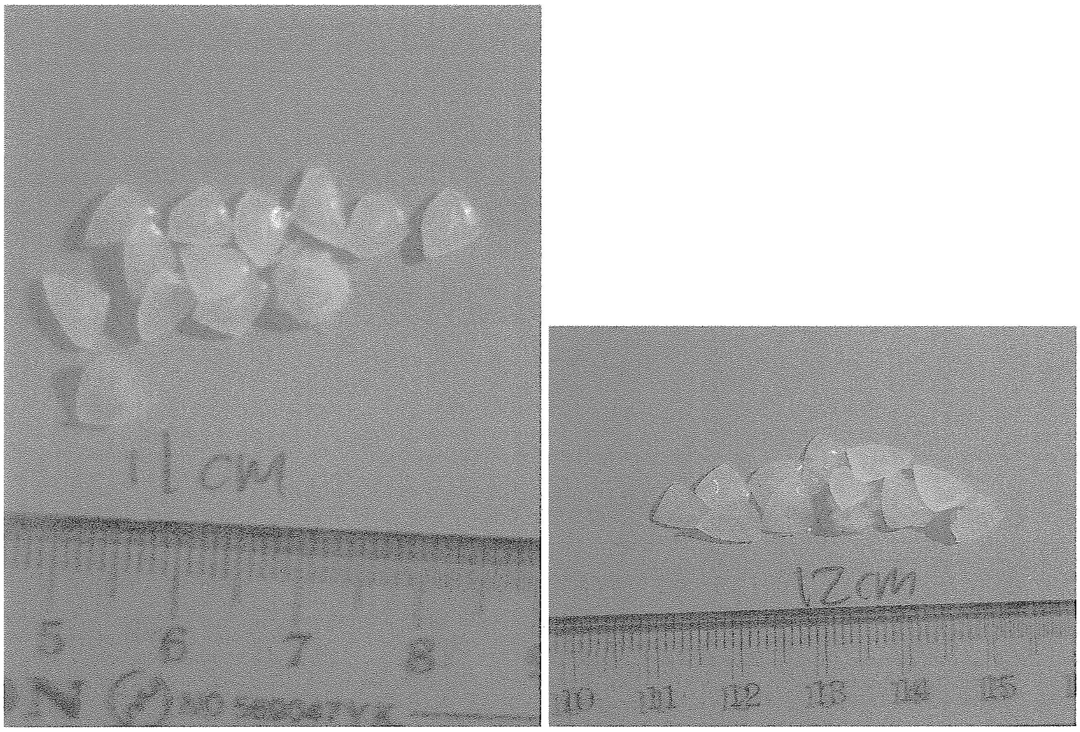

Figure eleven (i),(j): A photo of wax droplets formed from wax dripped from 11cm and 12cm.

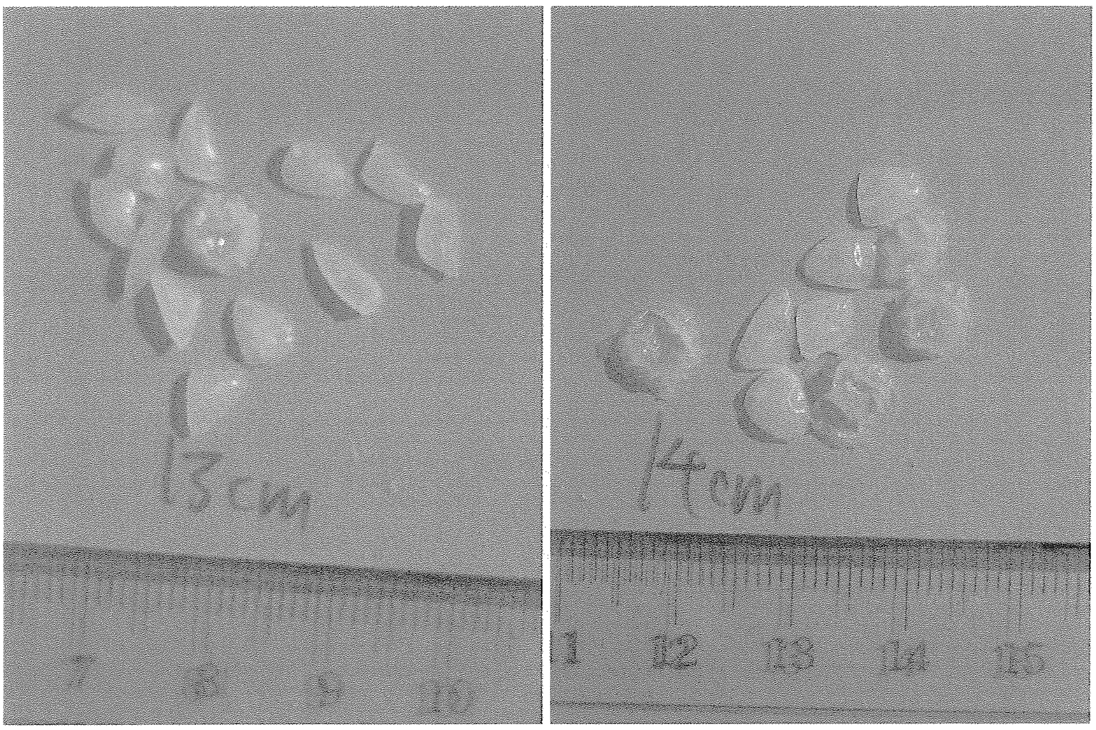

Figure eleven (k),(l): A photo of wax droplets formed from wax dripped from 13cm and 14cm.