

臺灣二〇〇六年國際科學展覽會

科 別：物理科

作 品 名 稱：Self Assembly Mechanism of Water Droplets

得 獎 獎 項：佳作

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圖左為王啓倫，圖右為王啓芸

我很喜歡做一些可以自己 DIY 的事情，像美工方面之類...所以以前有得過土工北市第二和紙工校內第一。當然我也很喜歡運動，尤其是籃球；在我國中的時候是再興的籃球隊隊長，高中部球隊教練有想找我入隊一起練球，但是因為爸媽反對，所以我還是把籃球當作一項休閒活動。另外我從小學二年級每年都有作科展直到現在，雖然有時實驗的進展不是很順利，但只要有了新發現而且是自己動腦想出來的話，就會非常有成就感。這次我覺得實驗做的滿完整的，希望評審教授也能給予意見與指導。(王啓倫)

從小喜歡探索問題，從生活中的小地方，發現無限的奧秘。我從小對繪畫和美工有很大的興趣，常常是學校海報設計的常勝軍，國二時，得到學生美展版畫類第三名。平時，除了讀書之餘，喜歡到郊外踏青，擁抱大自然，或是到博物館、美術館參觀、欣賞。國中開始和弟弟一起作科展，從中不但和弟弟的感情更好，對設計實驗、思考問題、撰寫報告也更上一層樓了。(王啓芸)

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Self Assembly
Mechanism of Water
Droplets

作品摘要

這是一系列關於水蒸氣冷凝為極細微小水珠的長程實驗。其中可以分為下列三個階段：

第一階段是基礎實驗。將水氣導入至潔淨的光滑表面上(蓋玻片)，觀察水珠冷凝的機制。

第二階段是在外加磁場及電場作用下，將水氣導入至潔淨的光滑表面(蓋玻片)，觀察水珠冷凝的機制。這部分的實驗推翻了一般「水分子是電中性，在電場或磁場中不受影響」的刻板觀念！實驗所呈現出來的冷凝水珠，不但有明確的自我組成模式(Self assembly pattern)。並且發現：**電場會增速凝結水珠的成長(Aggregation)**，而**磁場則會抑制凝結水珠的成長**。

第三階段是將水蒸氣導引至超聲波的環境中：我們先將超聲波訊號產生器(變頻、定頻)面向於載台旁，再讓水氣導入至潔淨的光滑表面上(蓋玻片)，觀察冷凝水珠的機制。當使用固定頻率超聲波波源，我們發現：**在超聲波場中水珠的成長會受到抑制，且成長速率會隨著頻率的升高而逐漸減小**。

第一階段與第二階段的實驗結果與討論已分別發表於2004年及2005年的台灣國際科學展覽報告中，本作品將詳述第三階段。

Abstract

This experiment explores the basic nature of the condensation of water vapor into droplets on the surfaces of cover glasses. This condensation occurs because of the difference in temperature between the water vapor and the cover glass. The condensation process is observed under a microscope. The growth of the droplets can be described as: nucleation, aggregation (piling up) and coalescence. The growth is irrelevant to surfaces or environments. It is found that the temperature difference of moist air over the cover glass do not affect the nucleation size of the droplets in simple plain surroundings; while the change of flow rate does. In general, the coalescence is speeded up at higher temperatures. Furthermore, the effects of electric fields , magnetic fields and ultrasonic waves are also studied. It can be observed that the size of water droplets become smaller and grow more uniformly under magnetic fields or imposed ultrasonic waves; also, the aggregation rate is decreased by imposed magnetic fields or ultrasonic waves, and it is increased by imposed electric fields. These effects of magnetic fields , electric fields and imposed ultrasonic waves might be related to the flow conditions and the vibration of surrounding air in the system. This experiment provides the first step in the understanding of the formation of water droplets and their self assembly mechanism in different environment.

壹、實驗動機

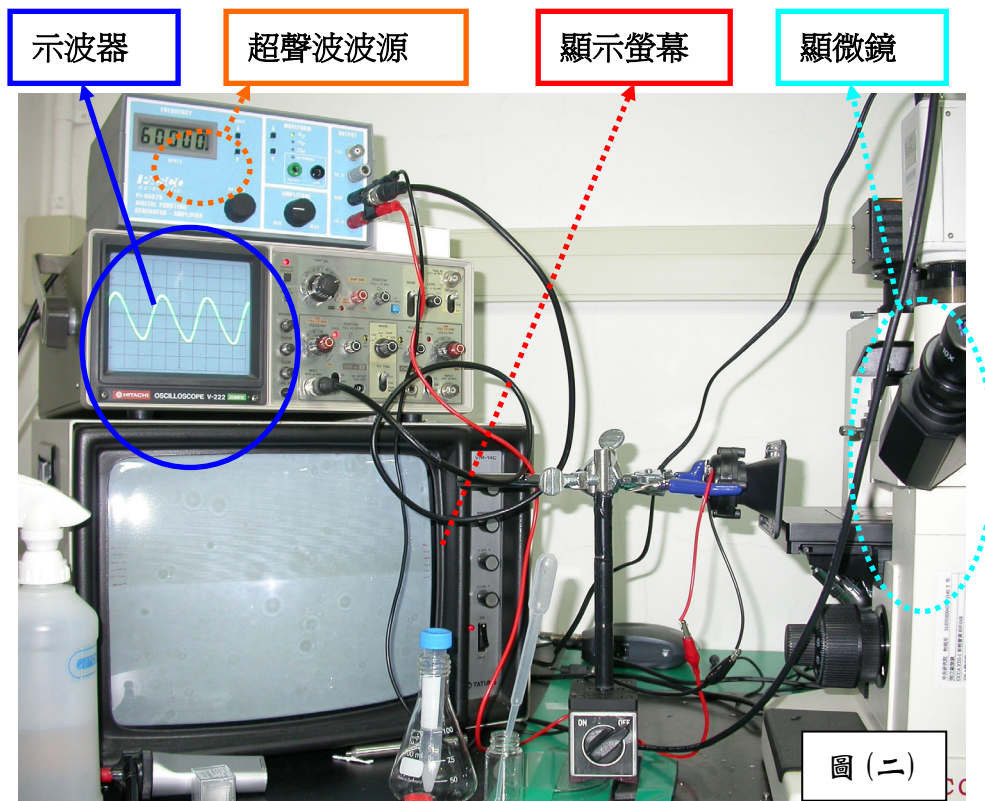
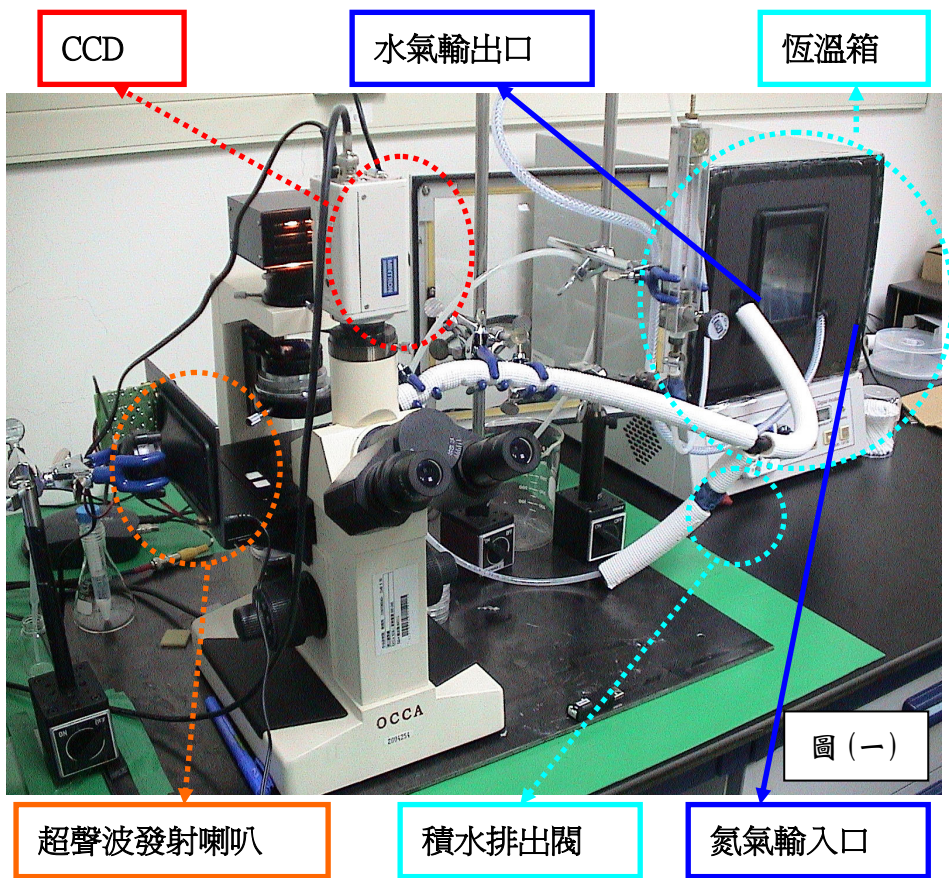
這是一個長期、系列性研究冷凝極細水珠的整體實驗。承接去年所作的實驗（第二階段），我們發現，當傳送水氣時，外加電場及磁場會影響水氣冷凝的過程。由於電場及磁場屬於超距力場，爲了釐清空氣在其中所扮演的角色，我們嘗試外加超聲波，觀察是否會影響水氣冷凝的過程。

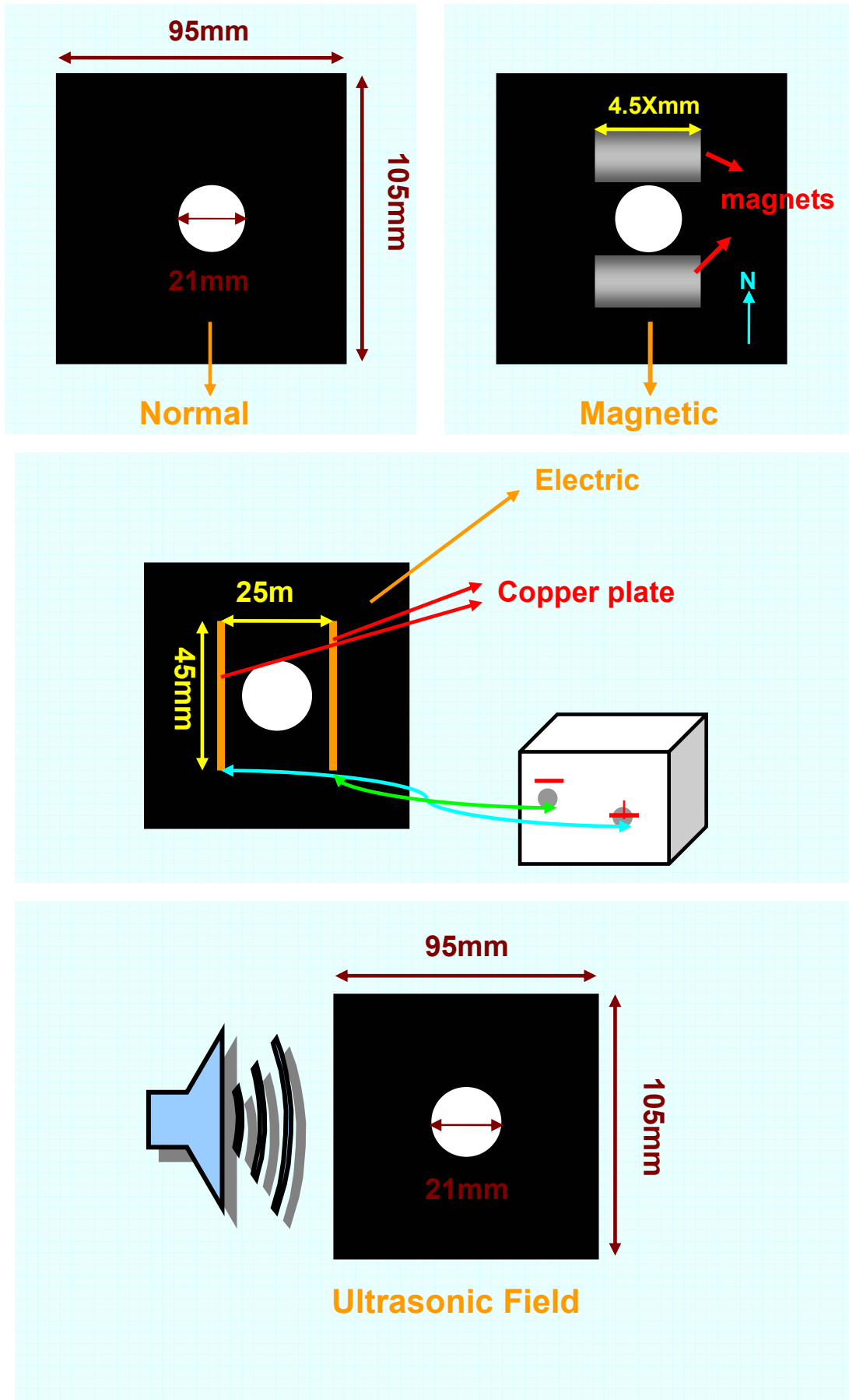
貳、研究目的

- （一）探討超聲波（變動頻率）對冷凝過程的影響
- （二）探討超聲波（固定頻率）對冷凝過程的影響

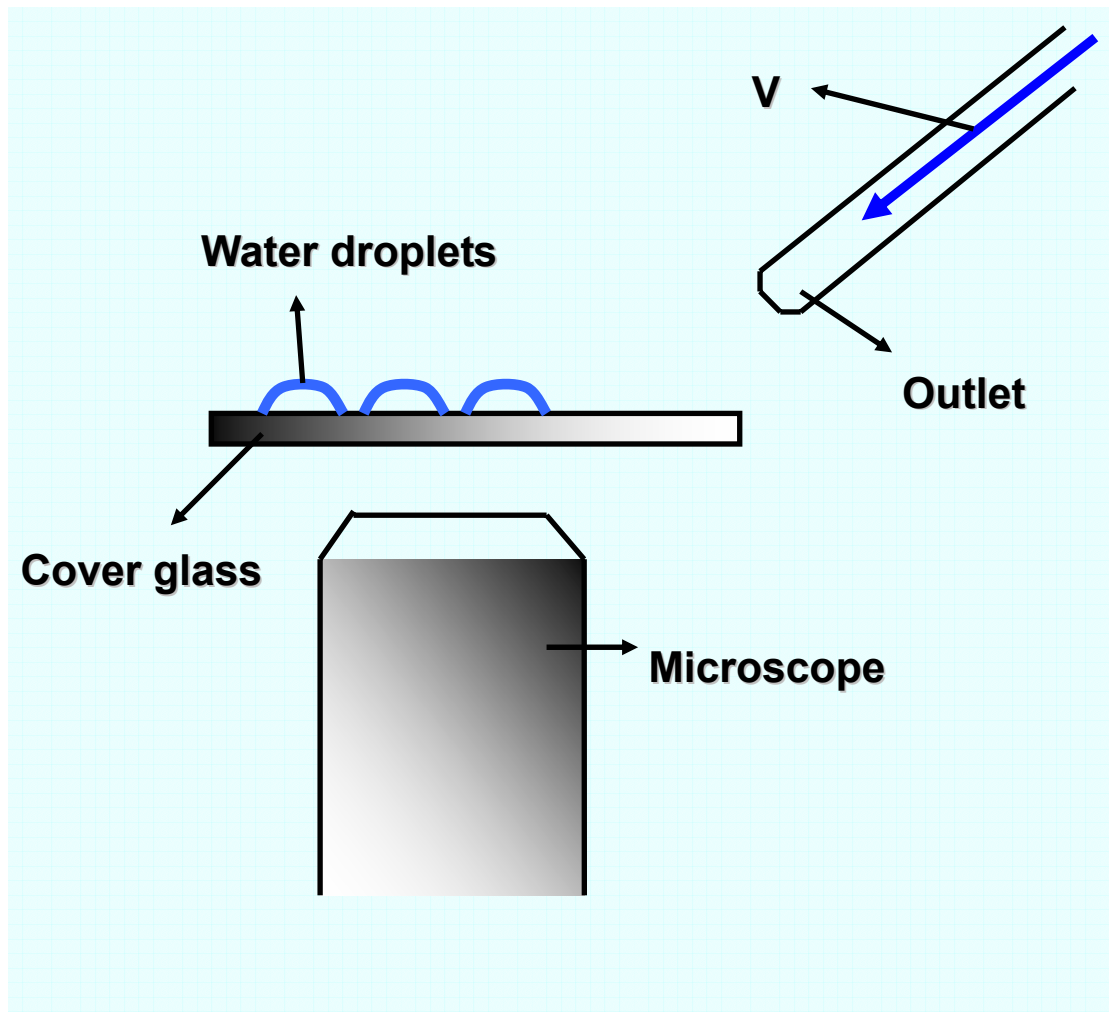
參、實驗方法

將潔淨過的蓋玻片(選用蓋玻片是爲了透光性良好和擺置的便利性)置於不同變因的實驗板上(我們將環境設爲—normal condition (control)、ultrasonic) 裝置示意圖，如(圖一)~(圖四)：

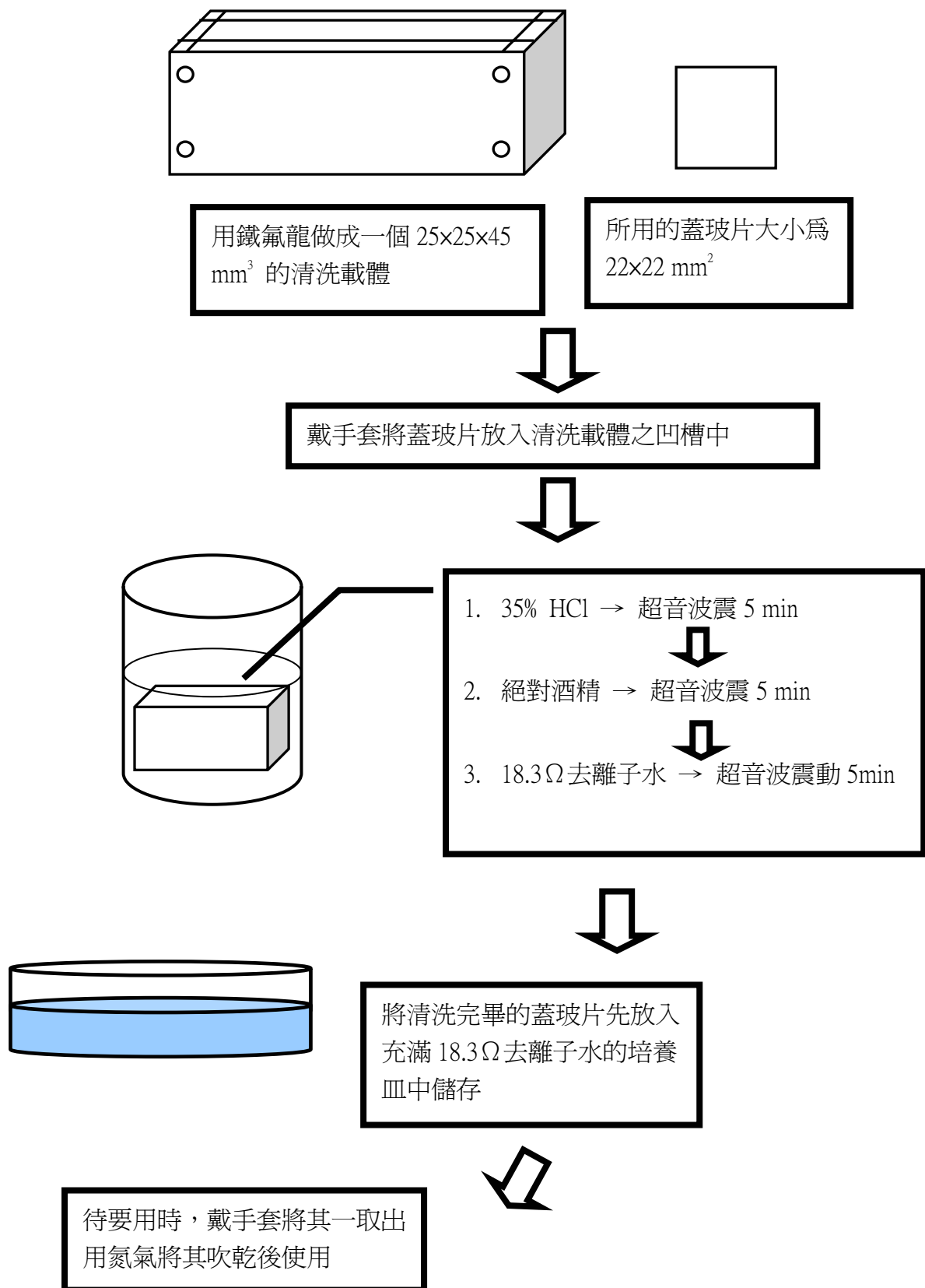




圖(三) 不同變因的台裝置



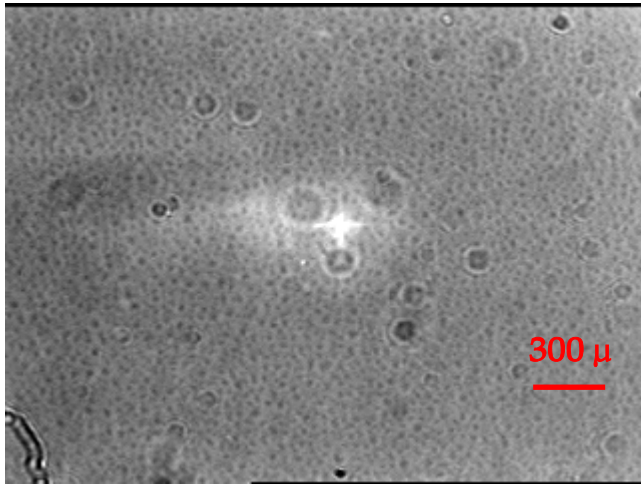
圖(四)吹送示意圖



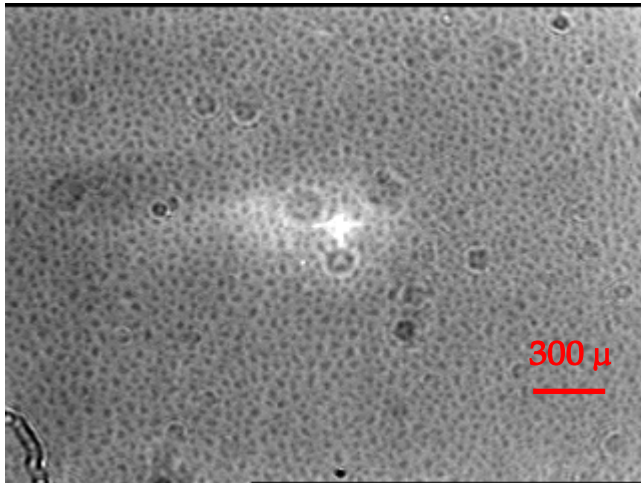
圖(五) 清洗流程

肆、實驗結果與討論

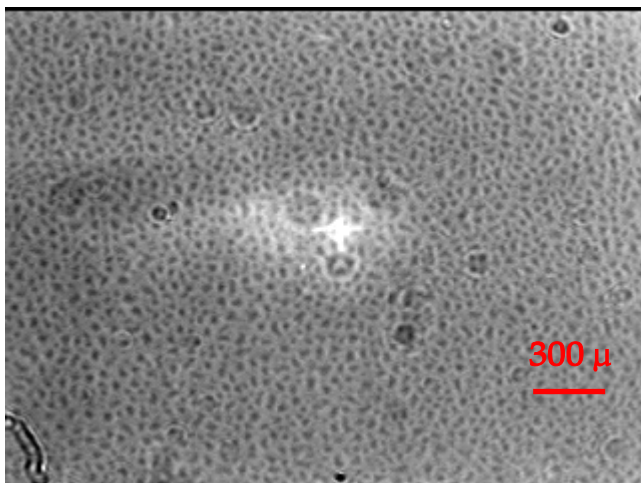
(一) 1、標準對照組(Control) 最初 0.2 秒內



T=0.134 s

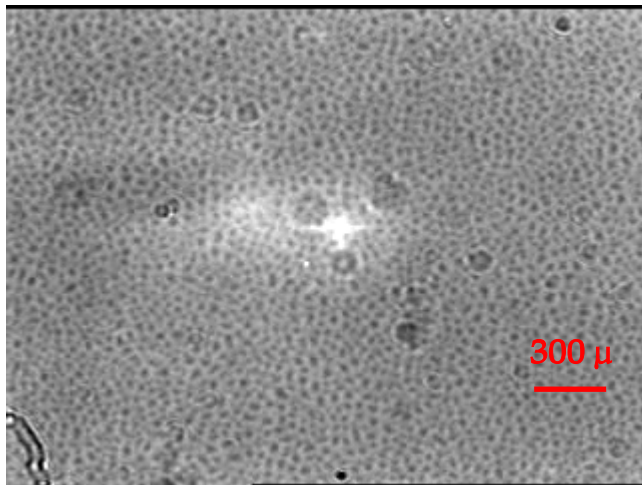


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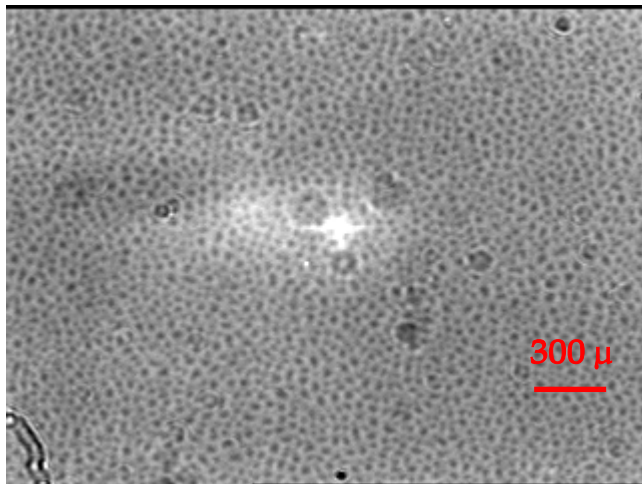


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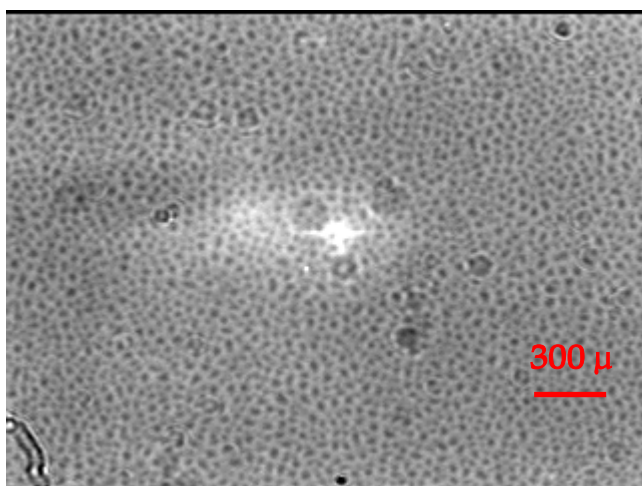
2、外加超聲波（變動頻率）55kHz~65kHz 最初 0.2 秒內



T=0.134 s

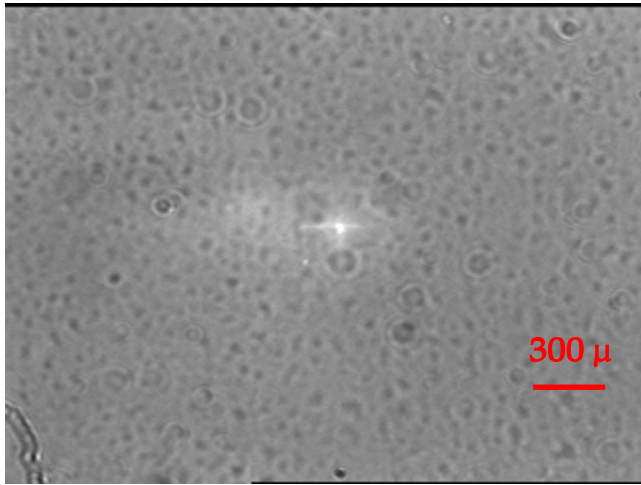


T=0.167 s

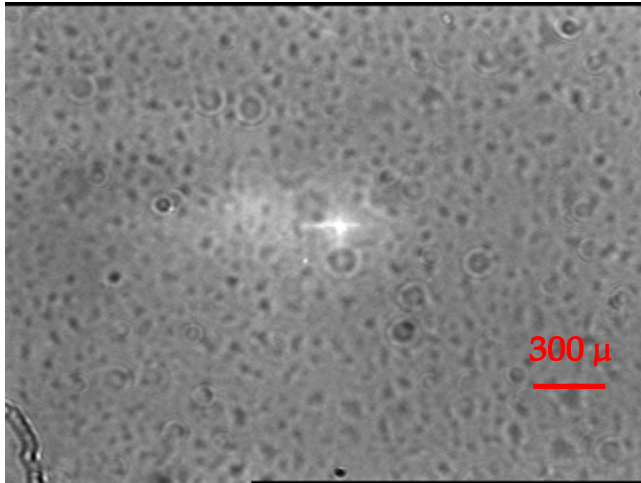


T=0.2

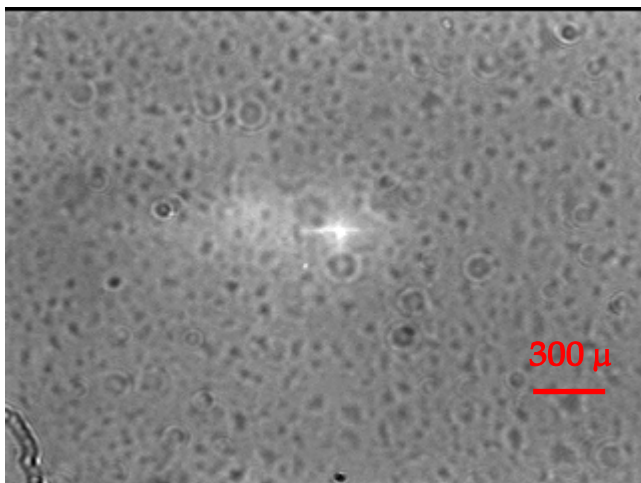
(二) 1、Normal condition (control)最初 0.2 秒内



T=0.134 s

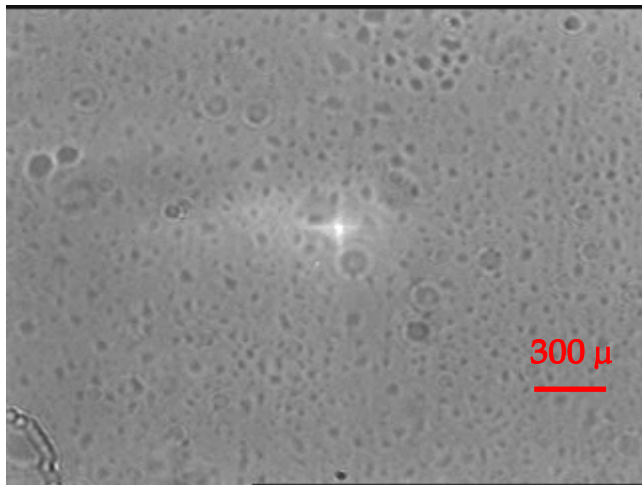


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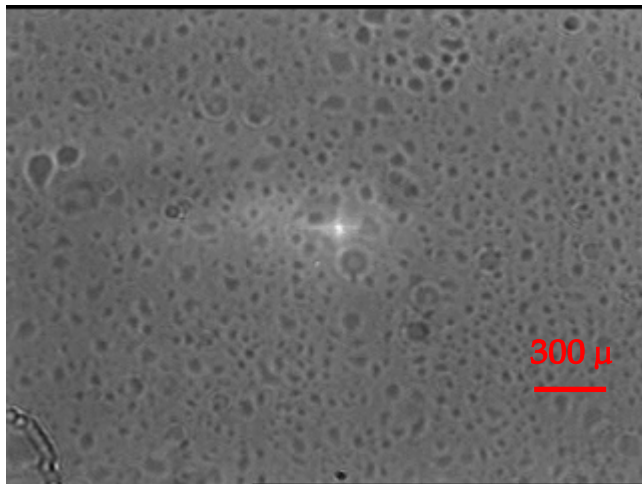


T=0.2 s

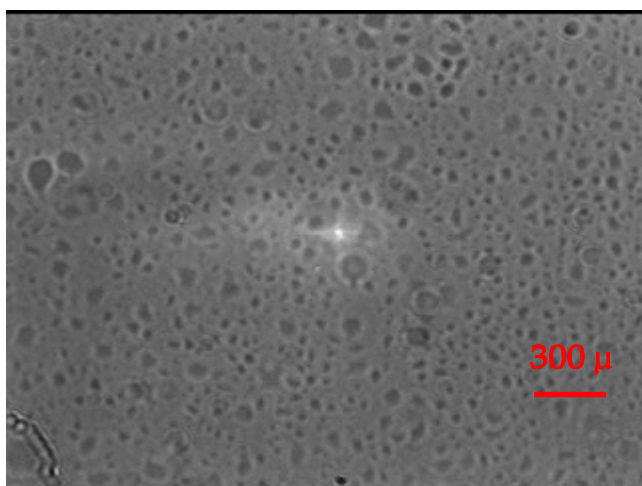
2、外加超聲波(固定頻率) 30kHz 最初 0.2 秒內



T=0.134 s

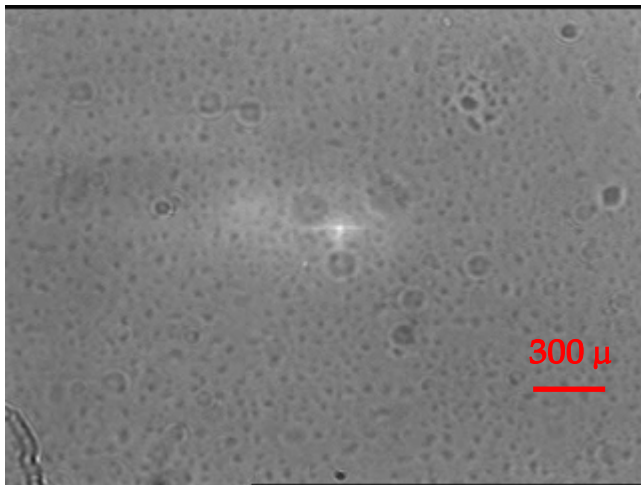


T=0.167

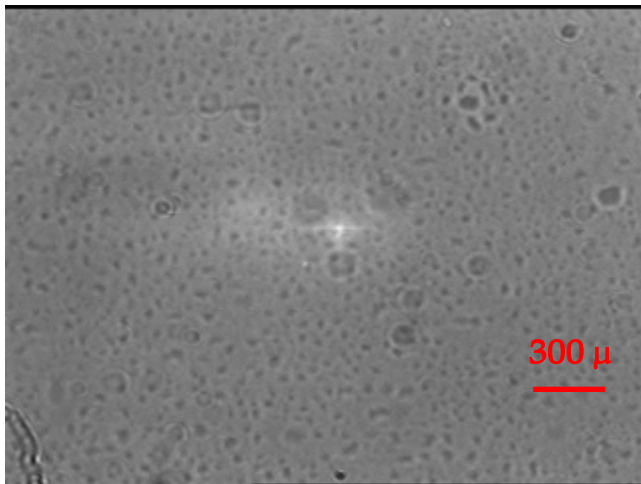


T=0.2 s

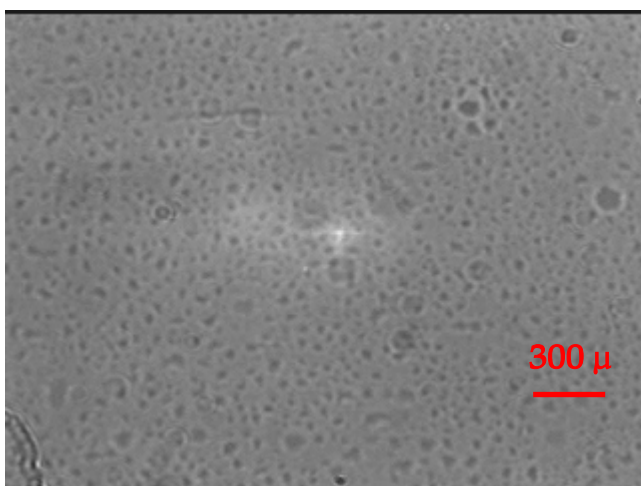
3、外加超聲波(固定頻率) 40k 最初 0.2 秒內



T=0.134 s

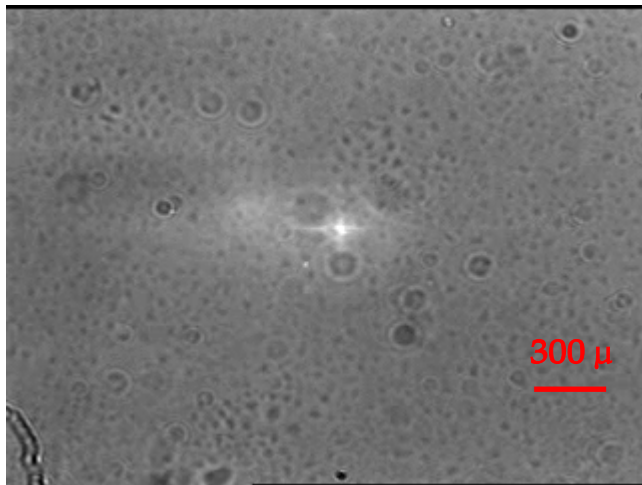


T=0.167 s

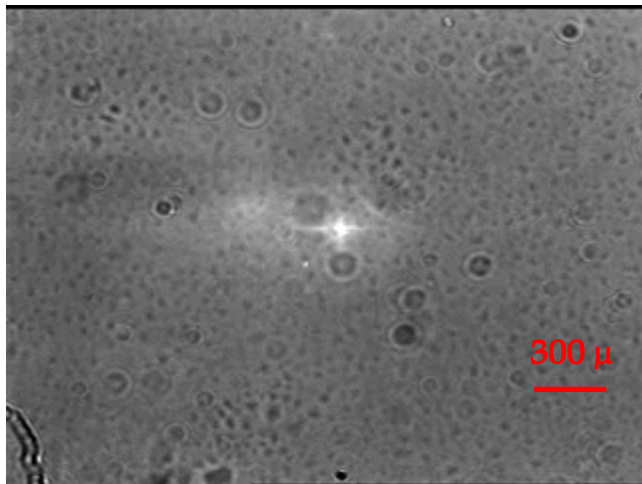


T=0.2 s

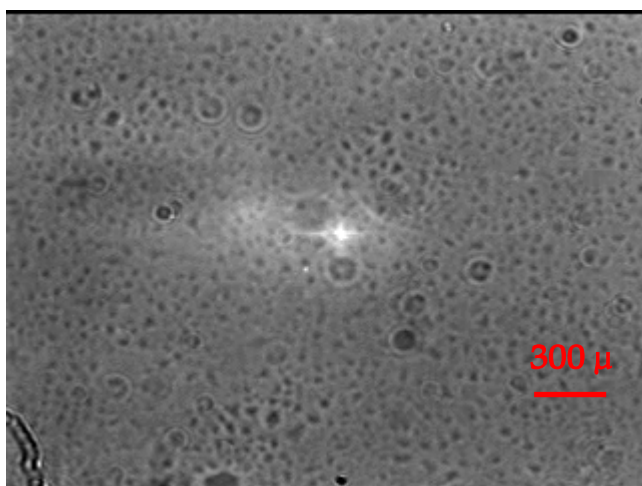
4、外加超聲波(固定頻率) 50k 最初 0.2 秒內



T=0.134 s

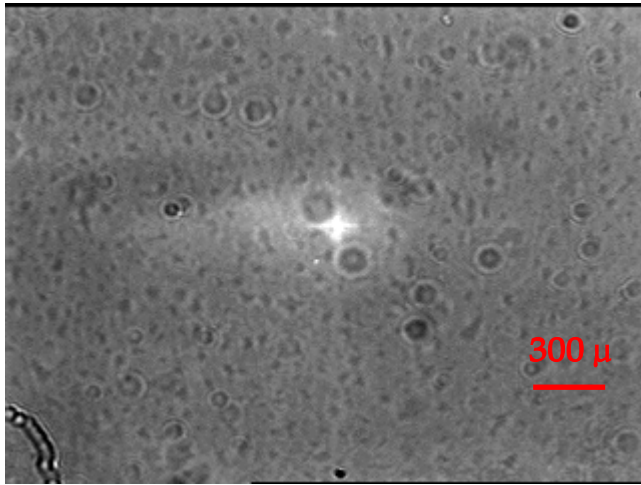


T=0.167 s

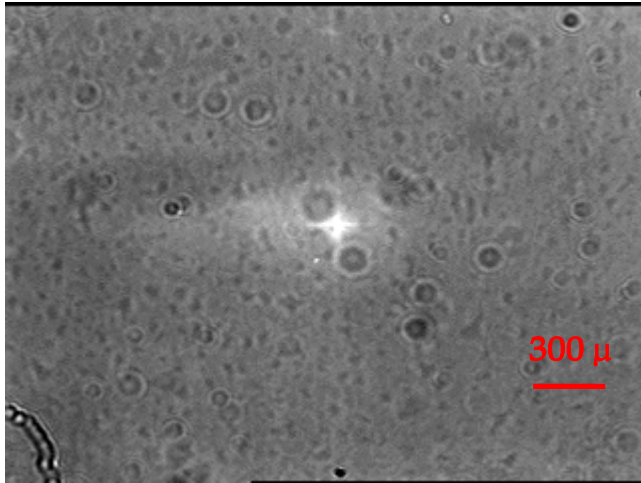


T=0.2 s

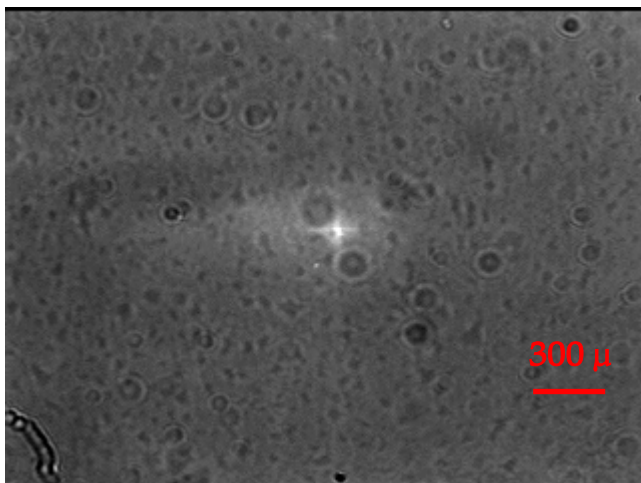
5、外加超聲波(固定頻率) 60k 最初 0.2 秒內



T=0.134 s



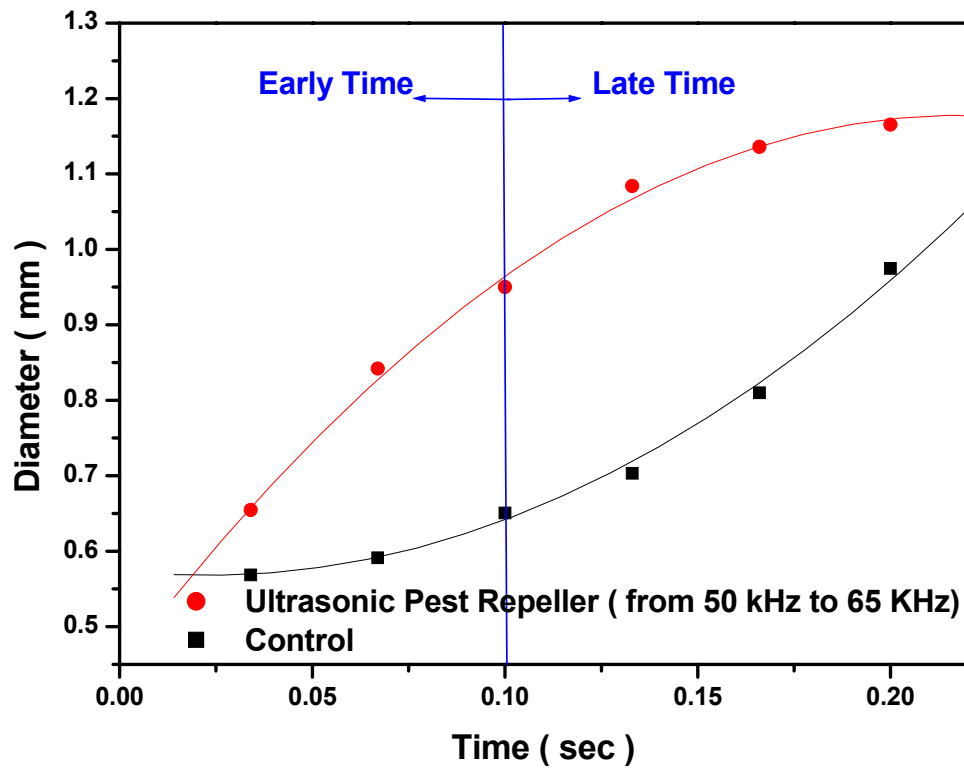
T=0.167 s



T=0.2 s

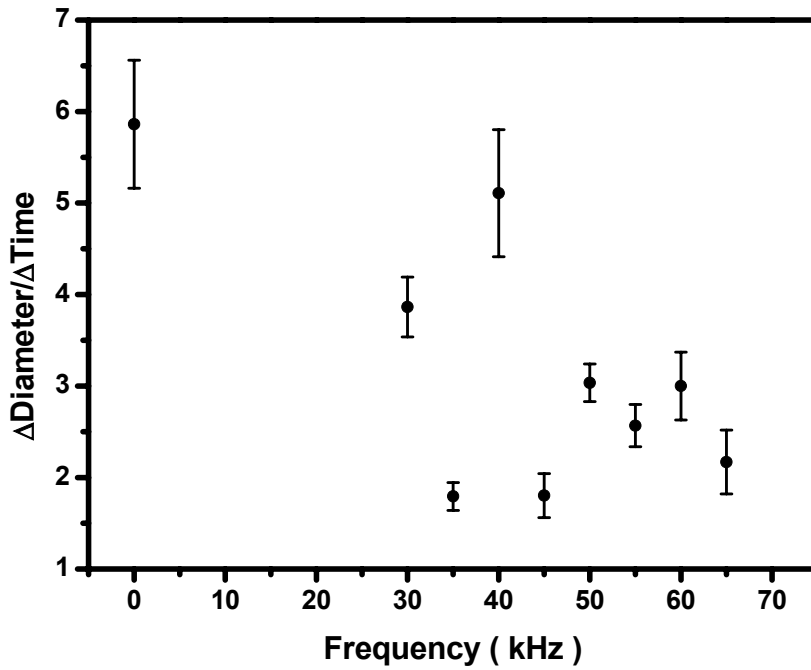
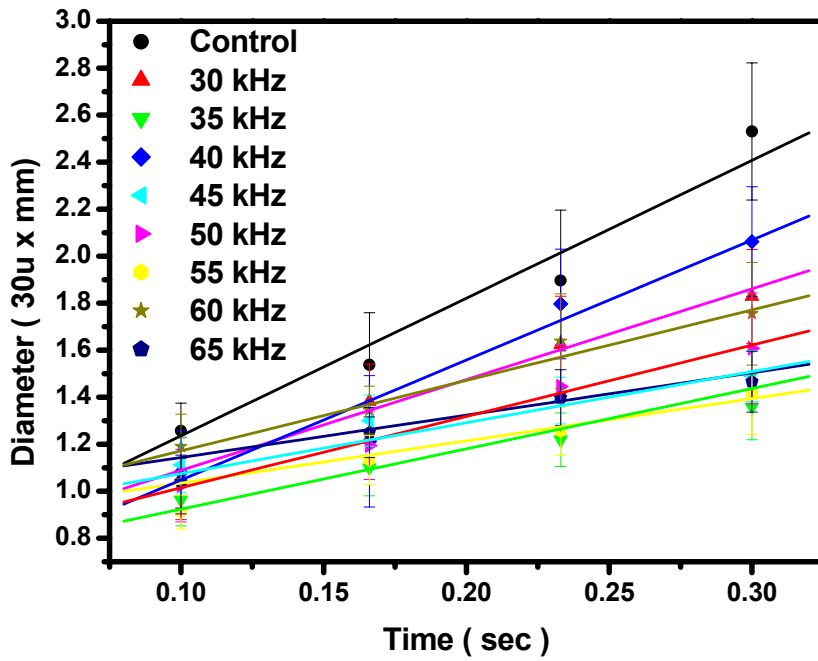
(三) 外加超聲波變動頻率 (from 55K to 65K) 與標準對照組：

(1) 經過 0.2 秒之後，外加超聲波 (變頻) 的冷凝水珠的直徑成長速率部份開始趨緩，而標準對照組則加速；這表示冷凝水珠在 Aggregation 過程會受到超音波場的影響：逐漸變慢。

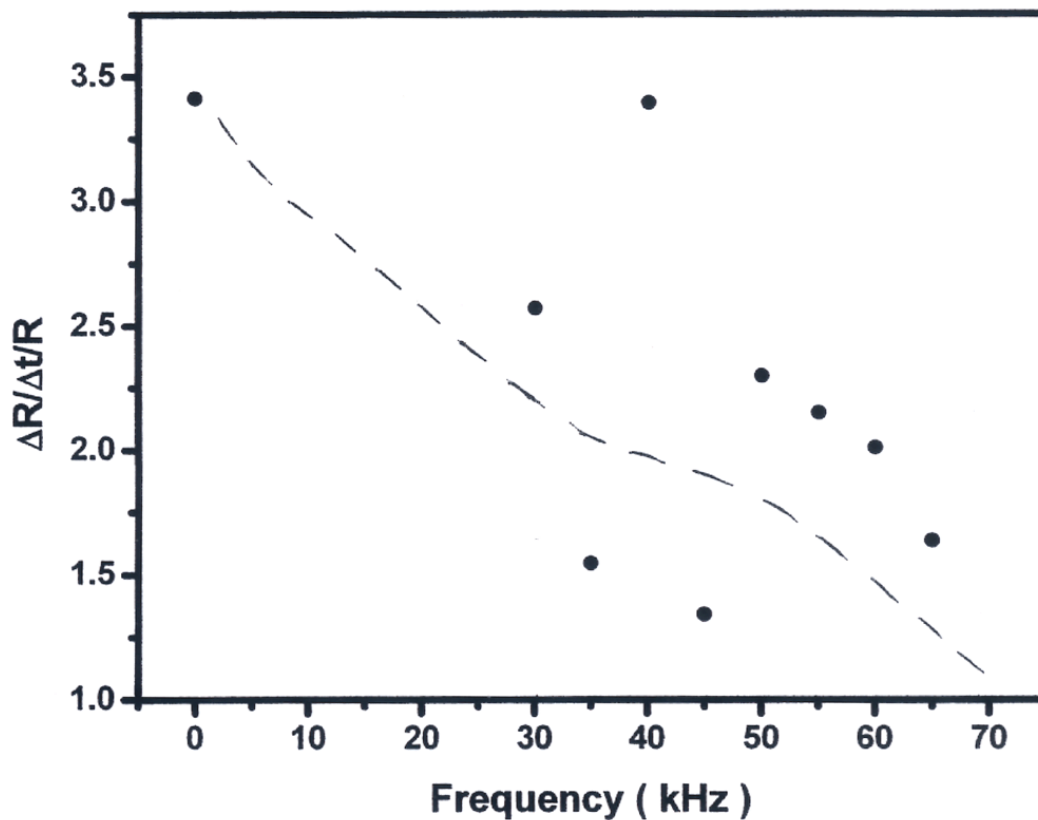


(2) 以 0.1 sec 為界，將 < 0.1 sec 作為 Early Time，將 > 0.1 sec 作為 Late Time。在 Early Time 時，Ultrasonic Pest Repeller (50~60 kHz) 的成長速率較快於 Control 的成長速率；但是，在 Late Time 時，則相反。

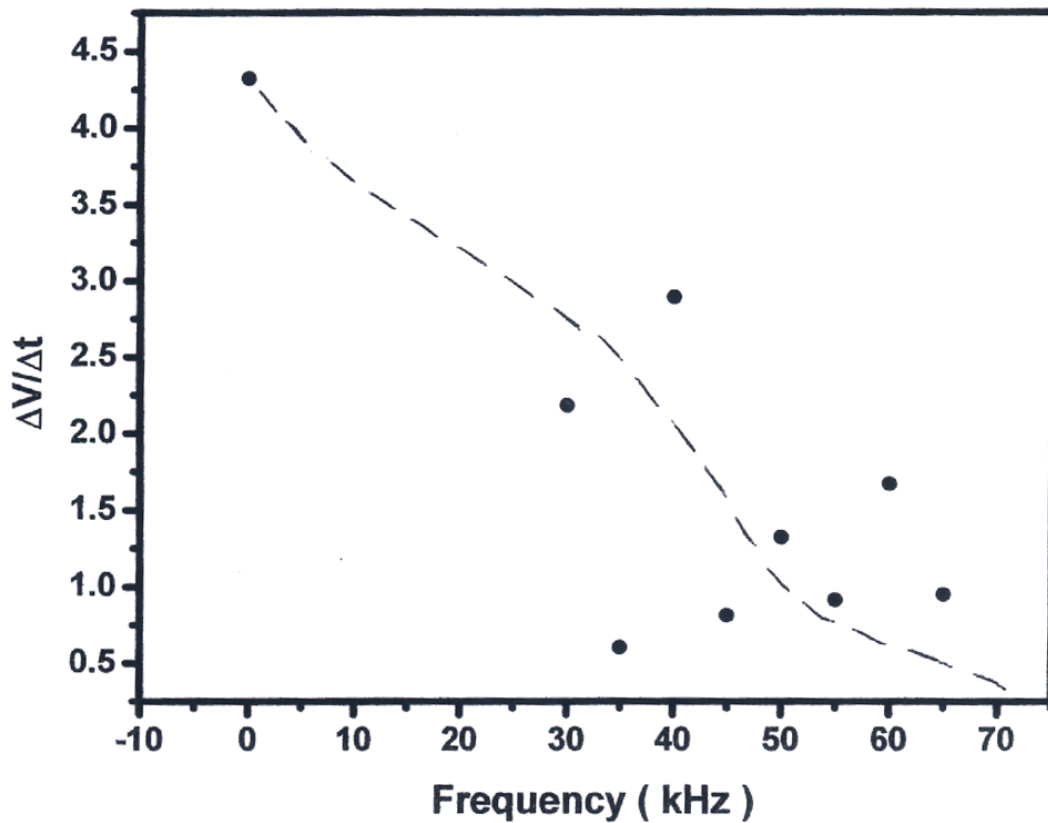
(四) 外加超音波固定頻率 (from 30K to 65K) 與標準對照組：



利用直徑變化對時間作圖得到不同頻率的斜率，以此斜率作為成長速率(Growth Rate)。趨勢漸向下，表示，外加超聲波，當頻率越強，水珠的成長速率減緩。此部份主要是探討 Late Time (> 0.1 sec)。



ΔR = 直徑變化， Δt = 時間變化， ΔR = 直徑平均值。利用 $\Delta R / \Delta t / \Delta R$ 可求出水珠相對成長速率(Size Growth Rate)，此趨勢也是向下，代表外加超聲波的頻率越大，水珠的成長速減緩。此部份主要是探討 Late Time (> 0.1 sec)。



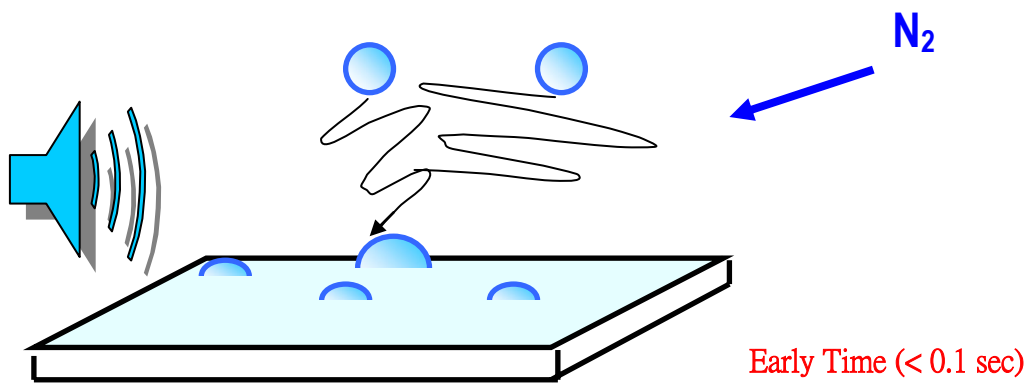
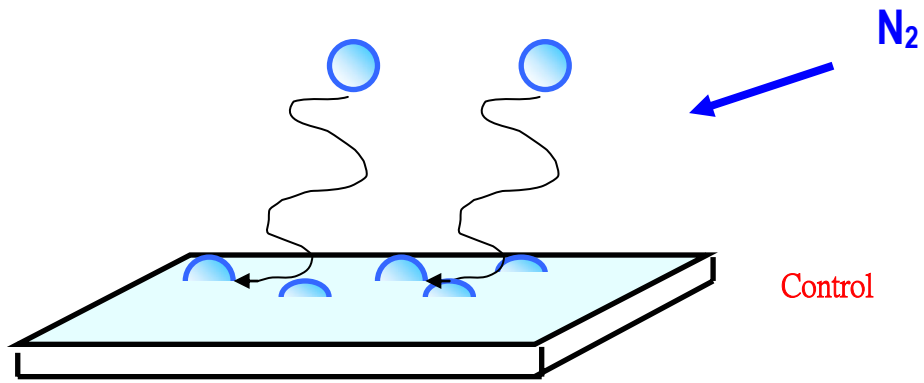
$\Delta V =$ 體積變化。假設體積為半球體($\frac{1}{2} \times \frac{4}{3} \pi r^3$)，一次微分後得 $4 \pi r^2$ ，則 $4 \pi r^2$

$\times \frac{\Delta R}{\Delta t}$ 為水珠體積成長速率。此趨勢也是向下，即可表示，水珠成長隨超聲波頻

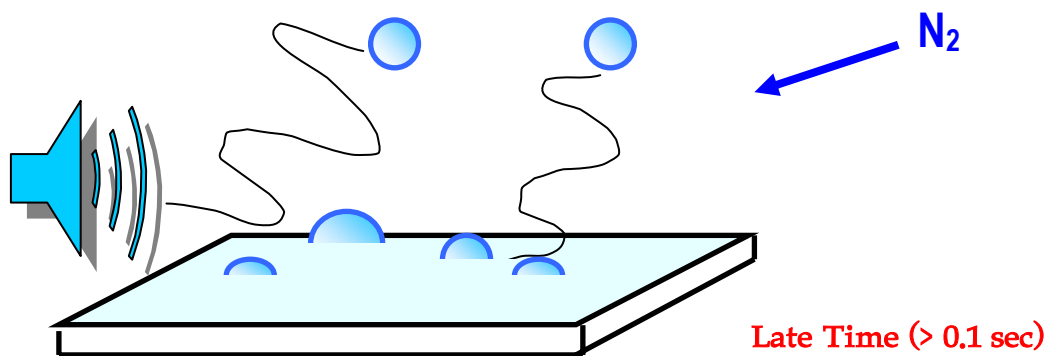
率的增強而減緩的趨勢。此部份主要是探討 Late Time ($> 0.1 \text{ sec}$)。

以 $R/t/R$ 和 V/t 分別作圖，可相互印證，外加超聲波，當頻率越大，水珠成長速率(Growth Rate)也隨之減緩。

在外加超聲波的情況下，其成長模式可分為兩種，分別為 Early Time ($< 0.1 \text{ sec}$) 和 Late Time ($> 0.1 \text{ sec}$)。推論：



外加超聲波的水珠成長速率較快。推測，因超聲波增加空氣中的擾動，而使水珠較容易碰撞，增加其質量，並間接加速其下降速率。(加速成核速率)



外加超聲波的水珠其成長較緩慢。推測，因空氣擾動持續增加，而使水珠移動範圍加大，故使冷凝於蓋玻片上的水珠密度下降，則觀察到的水珠生長速率減緩。

伍、結論

1. 成核 (Nucleation) 水珠的成長過程主要是由二部分組成的：
先堆疊 (Pile up → Aggregate) 後合併 (Coalescence)

2. 溫度相同時，水蒸氣的速度、外加磁場強度、外加電場強度、外加超聲波定頻不同時，影響成核尺寸 (Nucleation size)

3. 影響凝結水珠散佈於物體表面可能的方式：
 - (1) 空氣對流機制的影響
 - (2) 趨向最低能量
 - (3) 趨向最大亂度
 - (4) 空氣共振 (超聲波) 因素影響

4. 影響水珠尺寸的重要因素：
 - (1) 水蒸氣與凝結表面的溫度差距
 - (2) 水蒸氣導引的速率
 - (3) 水蒸氣每秒達凝結表面的數量
 - (4) 外加超聲波引起空氣共振

5. 外加超聲波，Early Time (< 0.1 sec) 加速水珠成核速率
Late Time (> 0.1 sec) 減緩水珠成長速率

參考資料

http://www.atmo.arizona.edu/students/courselinks/fall99/atmo171-mcc/atmo171_f99_10.html

PRECIPITATION

Precipitation is any form of water (liquid or solid) that falls from a cloud and reaches the ground. There are, obviously, lots of different types of precipitation: rain, snow, hail, sleet, etc.

Nucleation : The initiation of a phase change of a substance to a lower thermodynamic energy state. (i.e. vapor to liquid Condensation) ...
American Meteorological Society

When water vapor condenses or freezes, it prefers to condense or freeze onto something - it needs a surface (preferable some liquid water or ice already present). Away from the surface of the earth (in the "free atmosphere"), the only available surfaces are tiny solid particles suspended in the air (dust, smoke particles, sea salt, etc.) These are called **condensation nuclei**. They are generally quite small; typical sizes are 0.01 to 1 micrometers in diameter.

The formation of precipitation begins with the process of **nucleation**, which is the *deposition, freezing, or condensation* of water vapor in the free air onto condensation nuclei. Let's say you manage to get some water vapor to condense onto a condensation nuclei. What will determine whether this initial water droplet will continue to grow or not? The answer is that the relative humidity of the air around the droplet will determine its growth. If we assume the nuclei is "normal" (i.e. neither attracts nor repels water molecules), then

- IF $RH < 100\%$ ---> evaporation exceeds condensation -----> droplet will shrink
- IF $RH = 100\%$ ---> evaporation equals condensation -----> droplet will remain same size
- IF $RH > 100\%$ ---> condensation exceeds evaporation -----> droplet will grow

We see that under "normal" circumstances, drop growth by condensation or deposition will only occur when the environment is supersaturated - when $RH > 100\%$. This is fairly rare. How then will a cloud ever form?

The answer is that some condensation nuclei are **hygroscopic**, they attract water. Because they attract water molecules, hygroscopic nuclei allow drop growth to occur when RH is equal to or less than 100% . Thus these type of nuclei are very important for cloud formation.

It is common to observe tiny droplets of liquid water in clouds even when the temperature is below freezing. When liquid water is present at below freezing temperatures, it is called **super-cooled water**.

Remember that water molecules want to have surfaces to condense (or in this case, to freeze) onto - call them ice nuclei in this case. Since there are very few ice nuclei in a typical cloud, you end up with super-cooled water droplets hanging around looking for something to condense on. If it gets cold enough (below -39 C), these super-cooled water droplets will freeze even in the absence of ice nuclei. This is called **spontaneous nucleation**.

Drop growth by condensation or deposition of water vapor onto appropriate nuclei is very slow. Figure 7.1 in *Danielson* shows that it takes more than 2 hours to grow a 30-micrometer diameter cloud droplet from a condensation nucleus by condensation alone. We know from routine observations that a thunderstorm can form and produce rain in less time than this. How is this possible, given the fact that drop growth by condensation is so slow?

Growth by collision and coalescence (Warm rain process)

The handout distributed today shows that typical condensation nuclei are 0.1 to 1 micrometer in diameter. Typical cloud droplets are observed to be 1-30 micrometers in diameter. The smallest precipitation particles are about 0.2 millimeters in diameter (or about 200 micrometers), and they can be up to 5 millimeters (5000 micrometers) in size. Condensation and deposition alone can grow typical cloud droplets in a period of 20-120 minutes, but you would have to wait almost forever for these processes to produce a

precipitation-sized particle that is heavy enough to fall. Luckily, there are other ways to produce precipitation-sized particles that work much faster.

The growth of precipitation particles beyond the cloud droplet stage can be accomplished by the combined effects of **collision** and **coalescence**, and also by the **Bergeron** process (the three-phase process). Collision and coalescence involve interaction of liquid water droplets with other liquid water droplets - it is most important in clouds with temperatures above freezing - hence the name "warm rain process" (*Danielson* p. 190). The Bergeron process is most important in clouds with temperatures below freezing. It involves interactions between ice particles, super-cooled water, and water vapor - hence the name "three-phase process").

Collision is self-explanatory. Liquid cloud droplets carried by air motions within a cloud can collide. Obviously, the most effective type of collisions will involve one big droplet moving through a group of smaller droplets. If the droplets are all moving at different speeds, that will also increase the likelihood of collisions.

Coalescence refers to the fact that water is "sticky". If two water droplets come into contact (say by collision) then they will stick together and make one larger droplet. Not all droplets that collide will stick together - they could bounce off each other. Therefore, collision and coalescence are not an entirely efficient process. Furthermore, these colliding droplets will tend to limit the size that a precipitation particle can reach - no larger than about 5 millimeters in diameter.

<http://www.uccs.edu/~tchriste/courses/PHYS549/549lectures/nucleation.html>

The free energy of a droplet of radius R is the sum of the energy cost due to the surface tension, $4 \pi \sigma R^2$, and the energy gain due to the volume of the new phase, $-(4/3) \pi R^3 \Delta f$, where ρ is the density (mass per unit volume).

Nucleation details

When moving into a 2 phase region on phase diagram - how does the new phase form ?

Two issues:

1. Thermodynamics: Is nucleation possible ? (energy minimization)
2. Kinetics: How fast does it happen ? (nucleation rate)

Homogeneous Nucleation

vapor --> liquid (solid) for a pure water

Energy minimization involves two terms:

1. volume transition
2. surface formation

volume transition:

$$\Delta G = \frac{4}{3} \pi r^3 \Delta G_v$$

radius of liquid phase

change in free energy per unit volume

for this system, the activity is essentially the pressure (P)

$$\Delta G_v = \frac{kT}{\Omega} \ln \frac{P_s}{P_v}$$

where v is the atomic volume, P_s is the pressure above the liquid (solid), and P_v is the pressure in the vapor.

We want $P_v > P_s$ so that ΔG is negative

=> supersaturation provides the driving force.

surface formation:

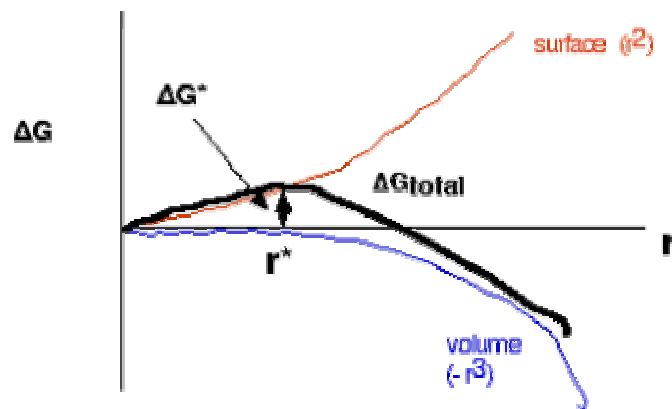
$$\Delta G_{surf} = 4\pi r^2 \gamma$$

← surface energy per unit area

Change in surface energy is always **positive** when forming surfaces.

Total energy change:

$$\Delta G_{total} = \frac{4}{3}\pi r^3 \Delta G_v + 4\pi r^2 \gamma$$



note:

- initial formation of nuclei has **increase** in G => metastable
- if $r < r^*$ then nuclei shrink to lower G
- if $r > r^*$ then nuclei grow to lower G
- r^* is a critical radius for nuclei

$$\text{find } r^* \text{ from } \frac{d\Delta G_{\text{total}}}{dr} = 0$$

$$\text{get } r^* = -\frac{2\gamma}{\Delta G_V}$$

$$\text{and } \Delta G^* = \frac{16\pi\gamma^3}{3(\Delta G_V)^2}$$

Films will also have an interface term => heterogeneous nucleation (coming soon!)

評語

本作品在今第三年度的研究中，探討超聲波對水滴形成、堆疊的影響。雖能從實驗上推論出超聲波會阻礙並降低水滴堆疊的行為，會有數據顯示超聲波頻率的效應，但實驗數據較不完整且其廣度應可大幅加強，以強化支持實驗結論，在實驗結論機制探討方面，比較缺乏許多可加強的空間。