Single Bubble Sonoluminescence Microgravity Experiment in 8 Minutes

MSS19B Thesis Project

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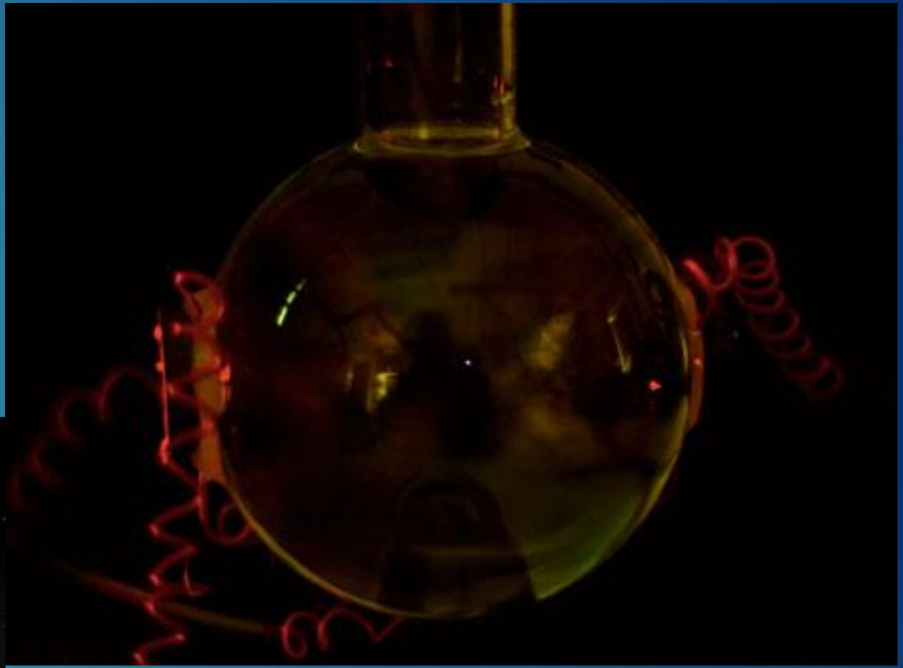
Outline

- What is Sonoluminescence?
  - Theories and Lab Based Experiment
- Microgravity Experiment
  - Why Microgravity?
  - Experiment Platform
  - The Scientific Aims

What is Sonoluminescence?

Acoustic Cavitation

- Creating light from sound
- Bubble or bubbles of air in a liquid
- Two main variants:
  - Single Bubble
  - Multi Bubble



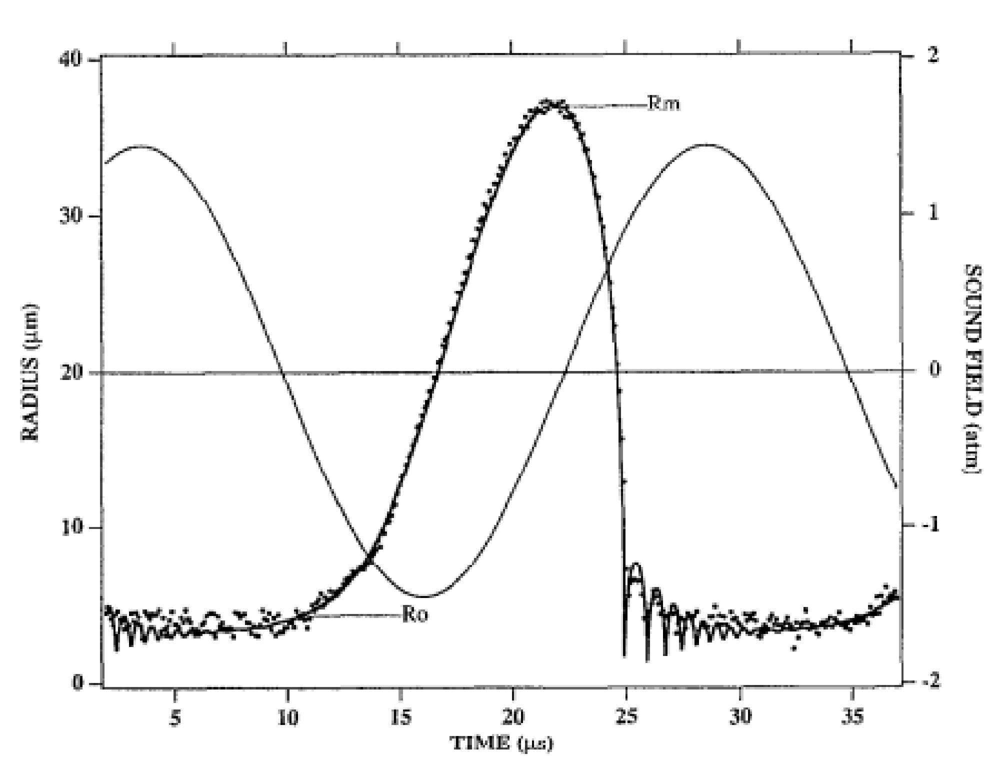
(Steer, 2007)

(Young, 2005)

Single Bubble Sonoluminescence

Typical Bubble Measurement

- Growth and collapse in cycle
- Equilibrium at 4µm
- Maximum at 35µm
- Minimum at 1µm
- Flash occurs lasting picoseconds
- Oscillates then stable for new cycle
- Freq≈25kHz for 100ml flask

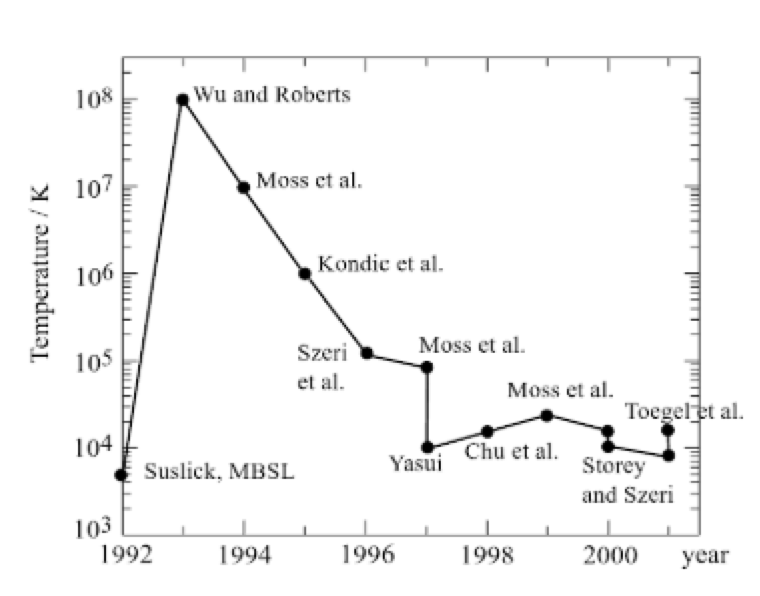


(Young, 2005)

Single Bubble Sonoluminescence

Source of the Flash

- As of 2000 were 16 competing theories
- As of 2015, two are mainstream
  - SL occurs due to extreme conditions inside bubble ionizing the gas
  - Most theoretical predictions estimate 10,000K
- Brenner in 2016, theory for 'cold' Sonoluminescence, due to timing of the flash
- Discharge of an excited cold condensate

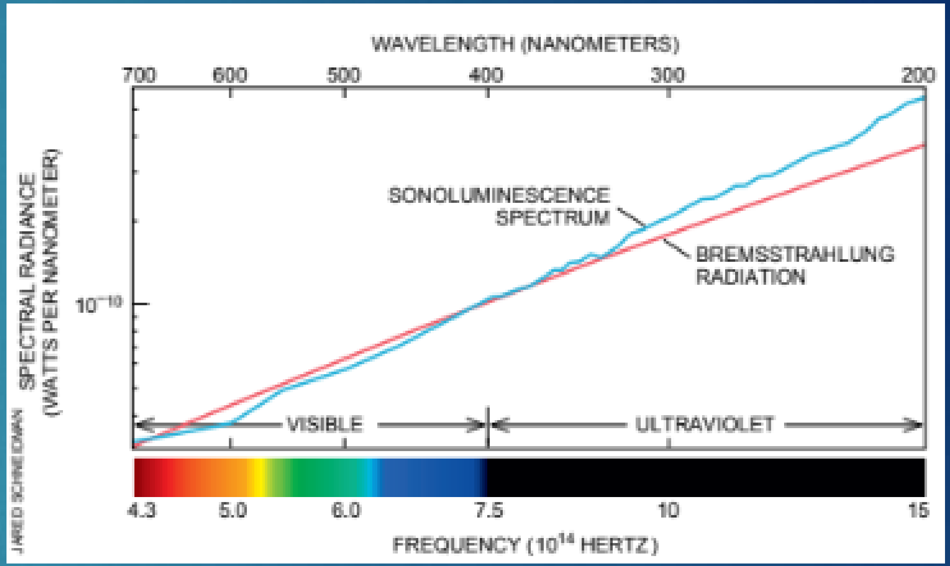


(Young, 2005)

Single Bubble Sonoluminescence

What is required?

- Highly spherical/symmetric resonator
- Liquid medium
- Degassed medium, 1/5th atm
- Presence of Argon
- Trapped bubble
- Need stable waveform

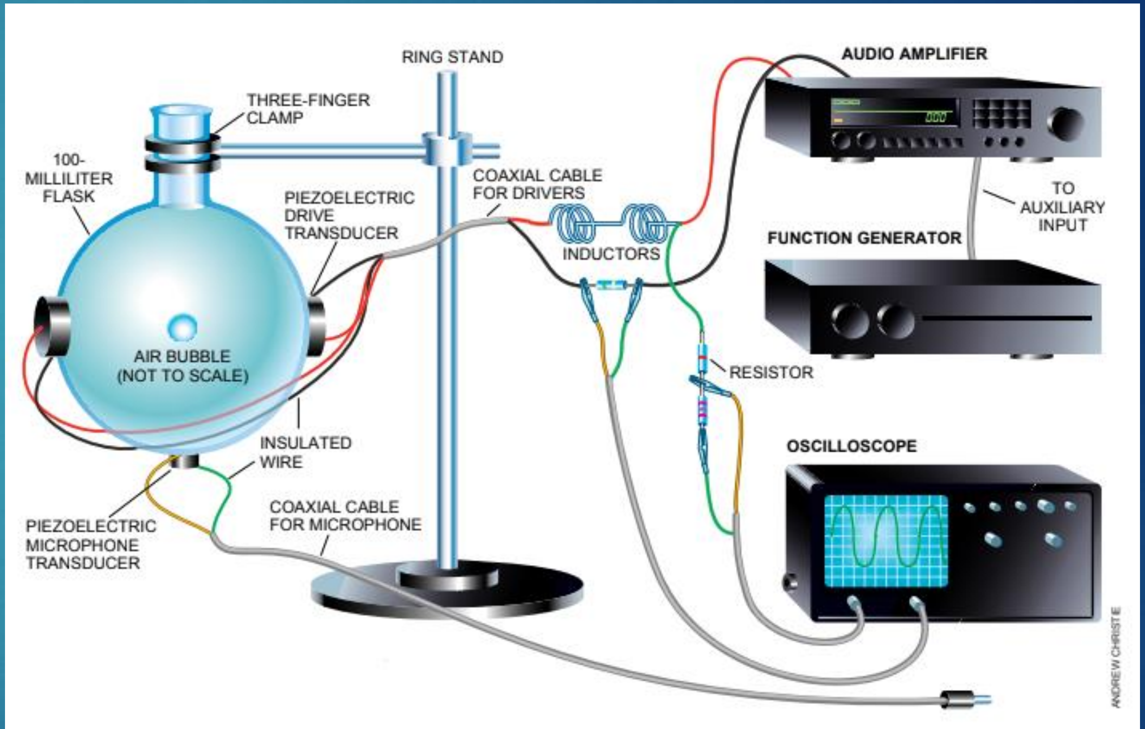


(Putterman, 1995)

Single Bubble Sonoluminescence

Typical Experiment

- Equipment:
  - Resonator
  - Piezoelectric Transducers
  - Variable inductor
  - Amplifier
  - Function Generator
  - Oscilloscope



(Putterman, 1995)

Experiment Development

100ml Experiment

Flask

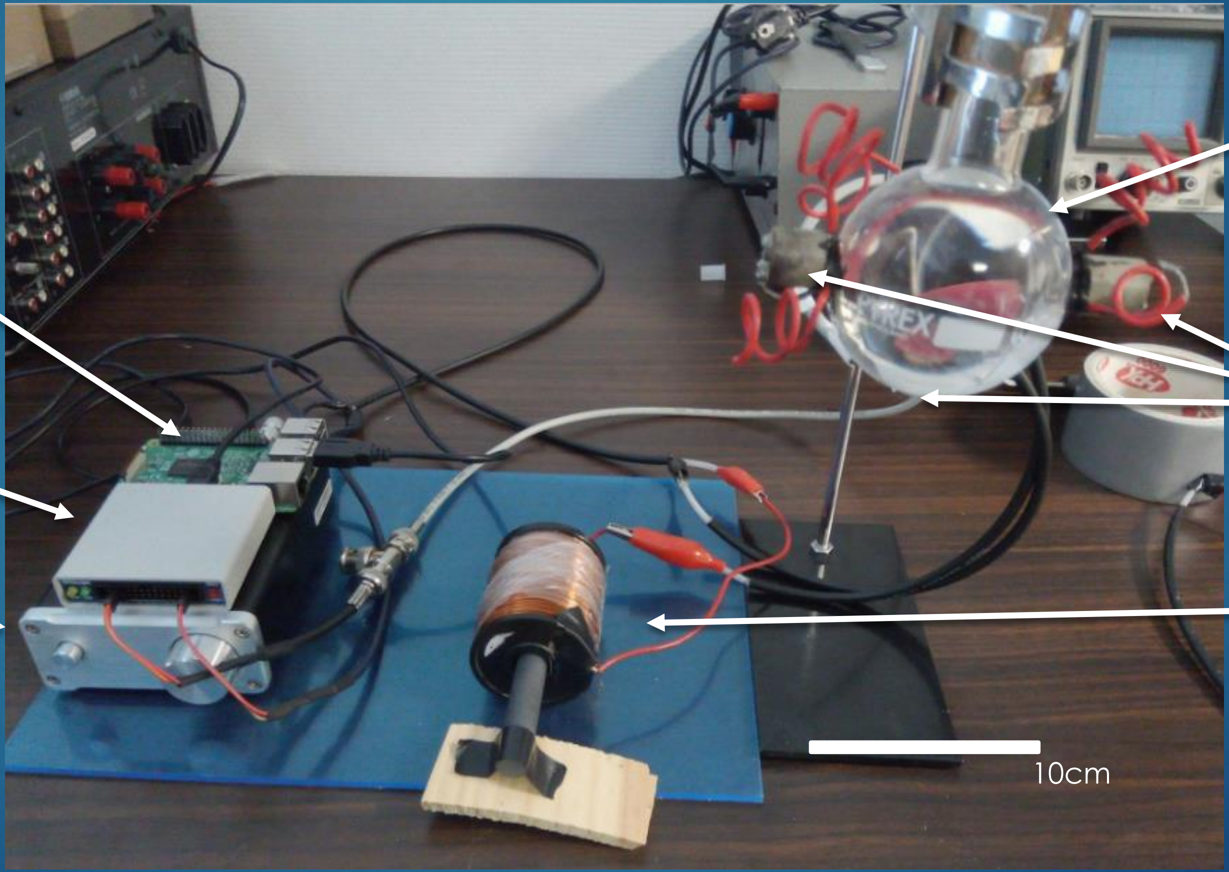
Raspberry Pi

Bitscope

Amplifier

Transducers

Variable Inductor



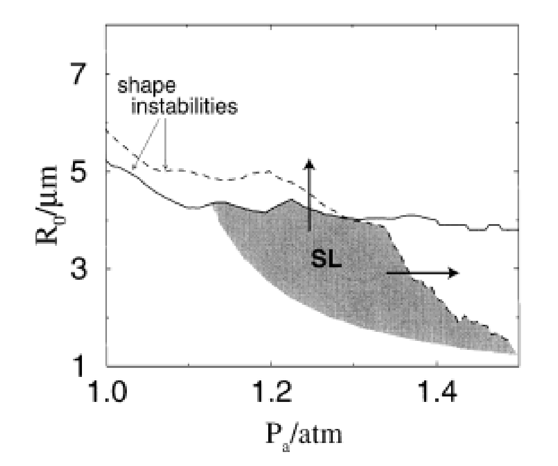
Results

100ml Flask Experiment Run

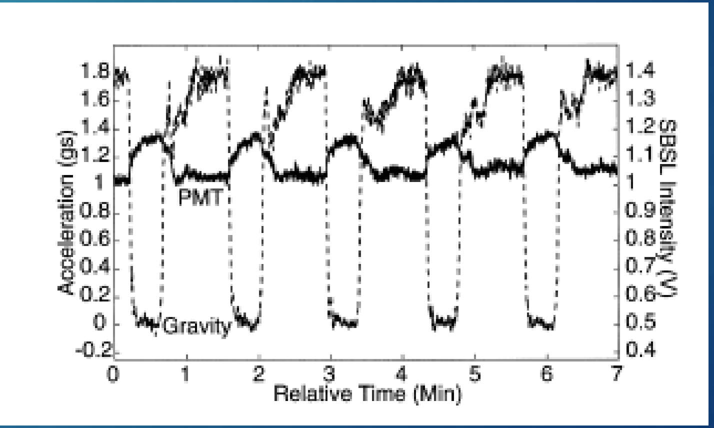
Microgravity Experimentation

Interest in Microgravity

- Current limitation is instabilities
- Driven by buoyancy, thereby gravity
- Microgravity improves intensity
- Preliminary parabolic flight experiment, Mantula in 2000
- 20-40% Increase in SL intensity



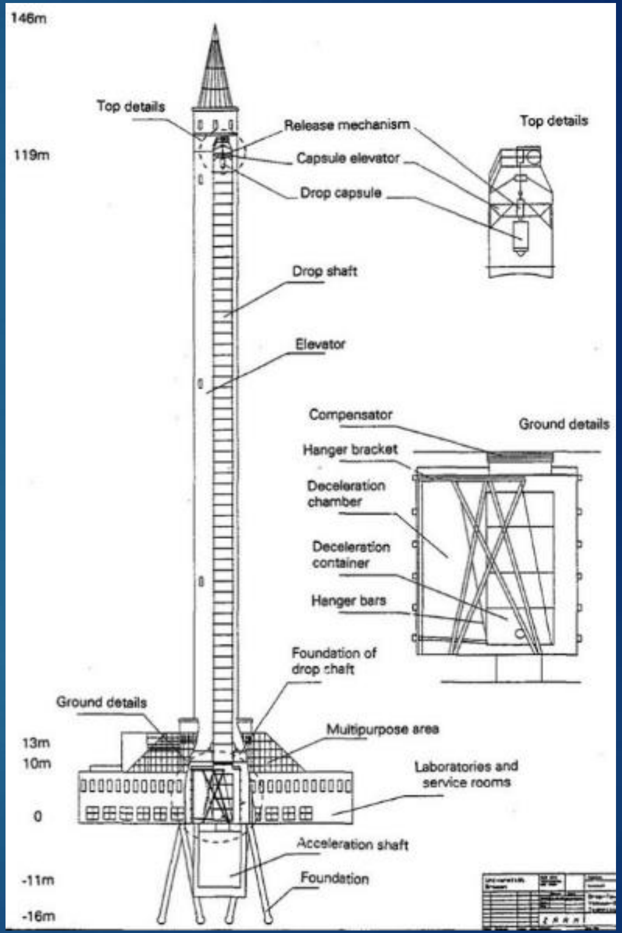
(Mantula, 2000)



Microgravity Experimentation

Experiment Platform

- Drop Tower (ZARM/ISU):
  - High quality
  - Repeatable, allows interaction with experiment
  - Timescale is suitable
- Consideration for ISS/Parabolic Flight
  - Low quality μg environment
  - Temperature control
  - EM shielding issue



(Zarm, 2018)

The International Space University

Microgravity Experimentation

- ISU's Drop Tower
    - 30x30x30cm
    - 2.5 m Drop
    - Providing ≈0.45 seconds of freefall
    - Quality of 10^{-2}g

Experiment Proposal

Scientific Aims

- Study the intensity of light emitted in the absence of gravity
  - Compare to preliminary parabolic flight study
  - Compare to light emission under the influence of gravity
- Study SBSL at driving pressures outside that for normal stable SBSL
  - Experimental evidence of bubble stability theory

Experiment Proposal

Scientific Value

- Low cost experiment with a high scientific return
- An undeveloped area of research
- Many open questions:
  - Source of light emission
  - Maximum driving pressure/light intensity
  - Validation of stability theory
- Develop understanding of conditions required for SBSL
- Step for future SBSL microgravity studies

SBSL Microgravity Experiment

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Summary

Why a SBSL Microgravity Experiment?

- Fascinating phenomena
- Very open area of investigation
- Comparative analysis to parabolic flight experiment
- Expect drop tower to produce better result
- Look into expanding the SBSL parameter space

References

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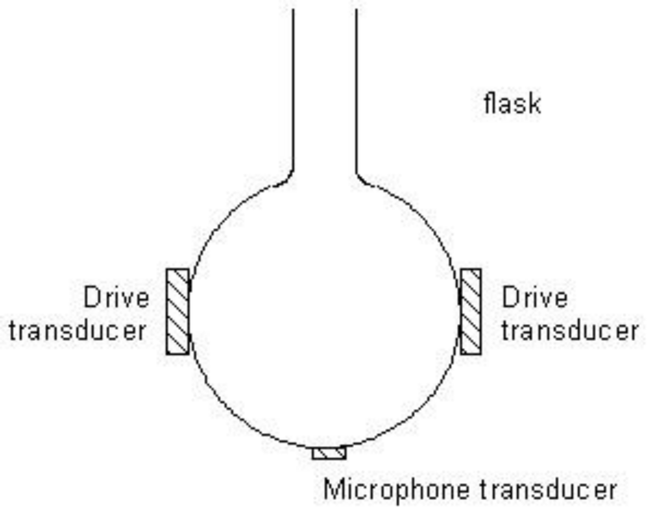
Questions?

Single Bubble Sonoluminescence

Typical Experiment

- Circuit Design
  - Set by the resonator
  - Vibrate at its resonant frequency
  - Set the apparatus to match this
  - Sets the electrical resonance required
  - Can be done with an RLC circuit



(Young, 2005)

$$f_{res} = \frac{c}{\lambda}$$

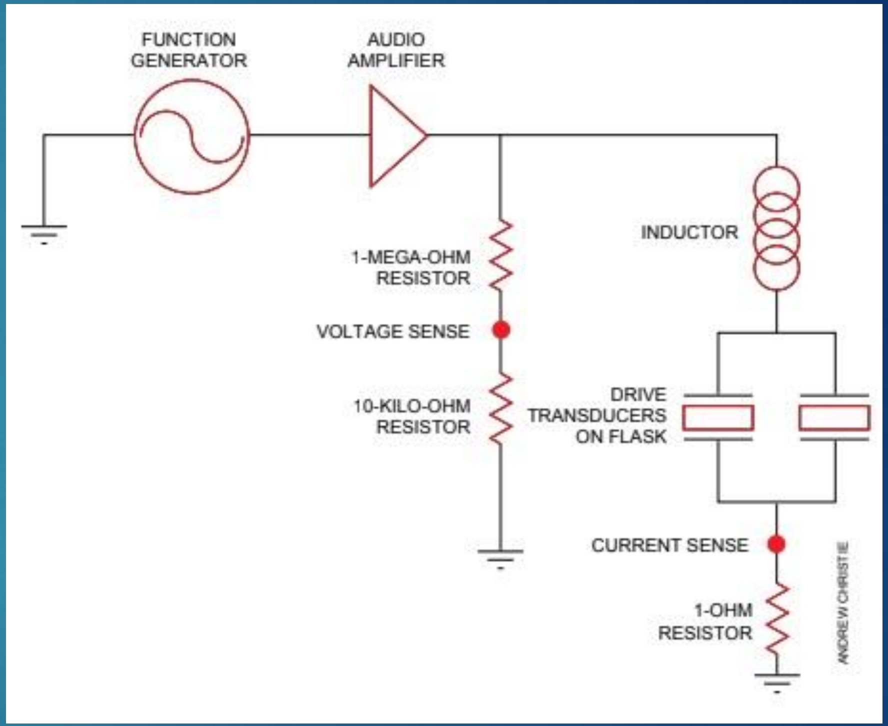
Single Bubble Sonoluminescence

Typical Experiment

- RLC Circuit
  - Inductor and capacitor in series
  - Forms an electrical resonance

$$f_{res} = f_{elec} \qquad L = \frac{1}{C(2\pi f_{elec})^2}$$

Flask	Res. Freq.	Capacitance	Inductance
250ml	19230kHz	195pF	351mH
100ml	26000kHz	195pF	191mH



(Putterman, 1995)

Single Bubble Sonoluminescence

Why the interest?

- Compression stopped at hard core van der Waals radius
- Potential for instigator for extreme chemical reactions

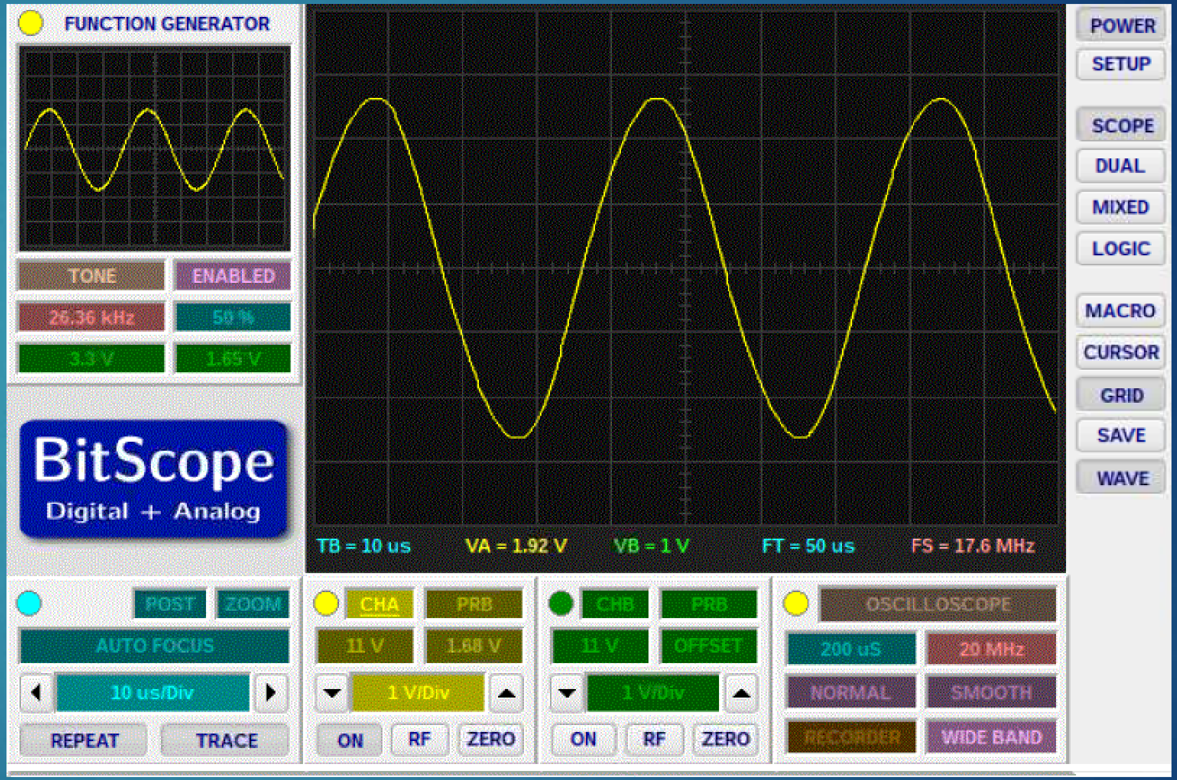
Time before min (ns)	Radius (um)	Velocity (m/s)	Temp (K)
60	13.7	-96.0	112.9
50	12.7	-107.3	130.5
40	11.6	-122.9	157.3
30	10.2	-146.3	200.6
20	8.6	-187.0	283.7
10	6.3	-283.7	520.5
5	4.6	-427.1	975.2

RPK Solution for a 8.5um bubble at P=1.4atm

Experiment Development

Microphone Output

- Aids in finding resonance
- DSO on the Bitscope
- At resonance

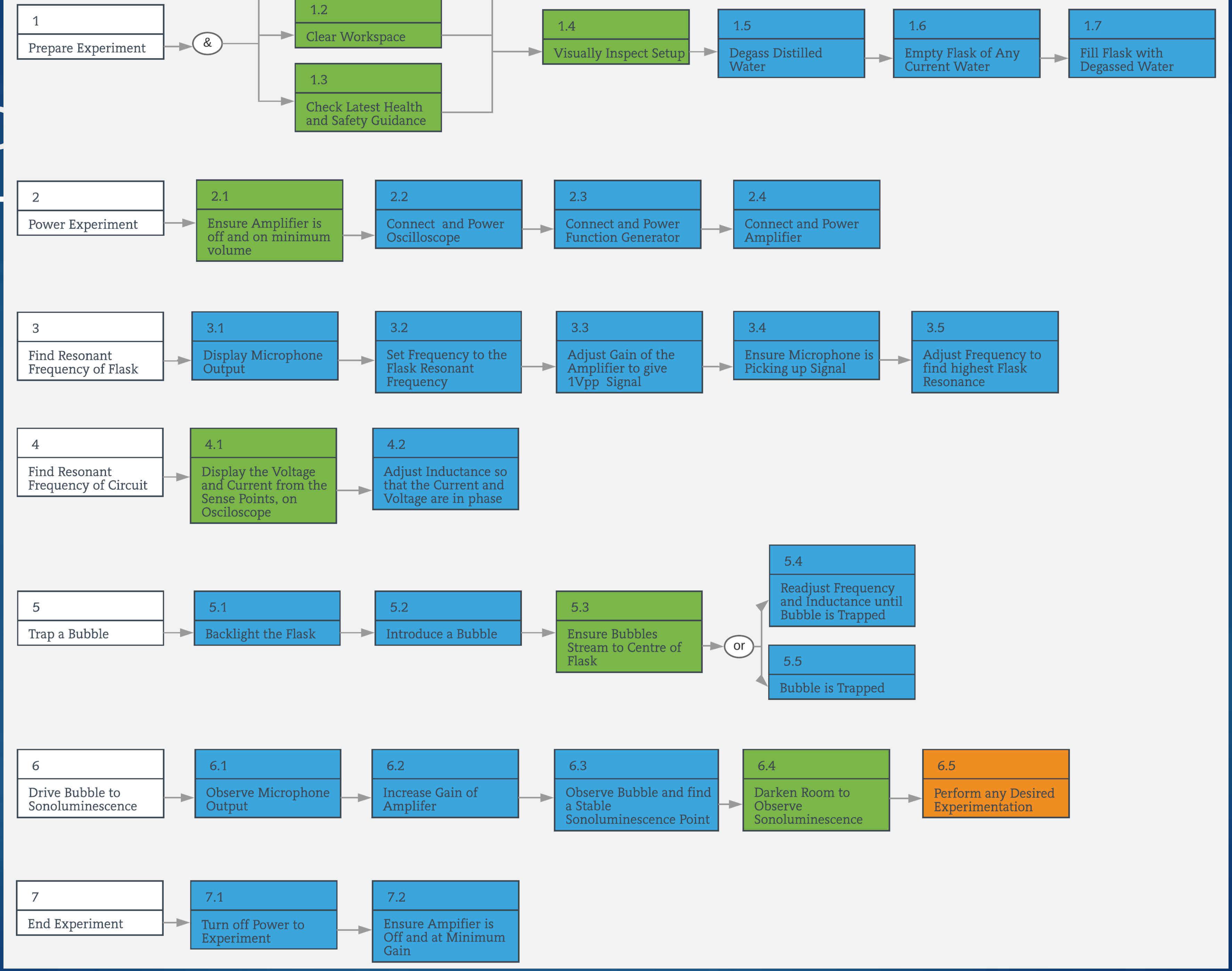


The measured microphone output signal

App

Funtional Flow- Top Level
1
Prepare Experiment
2
Power Experiment
3
Find Resonant Frequency of Flask
4
Find Resonant Frequency of Circuit
5
Trap a Bubble
6
Drive Bubble to Sonoluminescence
7
End Experiment
Funtional Flow- Second Level
1.1
Set up as per the Electrical Diagram
1.2
Clear Workspace
1.3
Check Latest Health and Safety Guidance
1
Prepare Experiment
&
1.4
Visually Inspect Setup
1.5
Degass Distilled Water
1.6
Empty Flask of Any Current Water
1.7
Fill Flask with Degassed Water
2
Power Experiment
2.1
Ensure Amplifier is off and on minimum volume
2.2
Connect and Power Oscilloscope
2.3
Connect and Power Function Generator
2.4
Connect and Power Amplifier
3
Find Resonant Frequency of Flask
3.1
Display Microphone Output
3.2
Set Frequency to the Flask Resonant Frequency
3.3
Adjust Gain of the Amplifier to give 1Vpp Signal
3.4
Ensure Microphone is Picking up Signal
3.5
Adjust Frequency to find highest Flask Resonance
4
Find Resonant Frequency of Circuit
4.1
Display the Voltage and Current from the Sense Points, on Osciloscope
4.2
Adjust Inductance so that the Current and Voltage are in phase
5
Trap a Bubble
5.1
Backlight the Flask
5.2
Introduce a Bubble
5.3
Ensure Bubbles Stream to Centre of Flask
or
5.4
Readjust Frequency and Inductance until Bubble is Trapped
5.5
Bubble is Trapped
6
6.1
6.2
6.3
6.4
6.5

App



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&
1.2
Clear Workspace
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1.4
Visually Inspect Setup
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Degass Distilled Water
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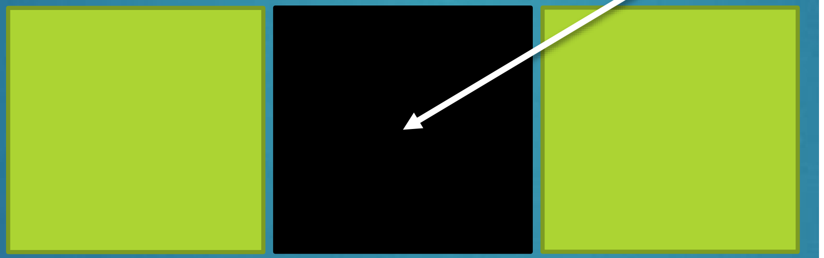
Ensure Bubbles Stream to Centre of Flask
or
5.4
Readjust Frequency and Inductance until Bubble is Trapped
5.5
Bubble is Trapped
6
Drive Bubble to Sonoluminescence
6.1
Observe Microphone Output
6.2
Increase Gain of Amplifier
6.3
Observe Bubble and find a Stable Sonoluminescence Point
6.4
Darken Room to Observe Sonoluminescence
6.5
Perform any Desired Experimentation
7
End Experiment
7.1
Turn off Power to Experiment
7.2
Ensure Ampifier is Off and at Minimum Gain

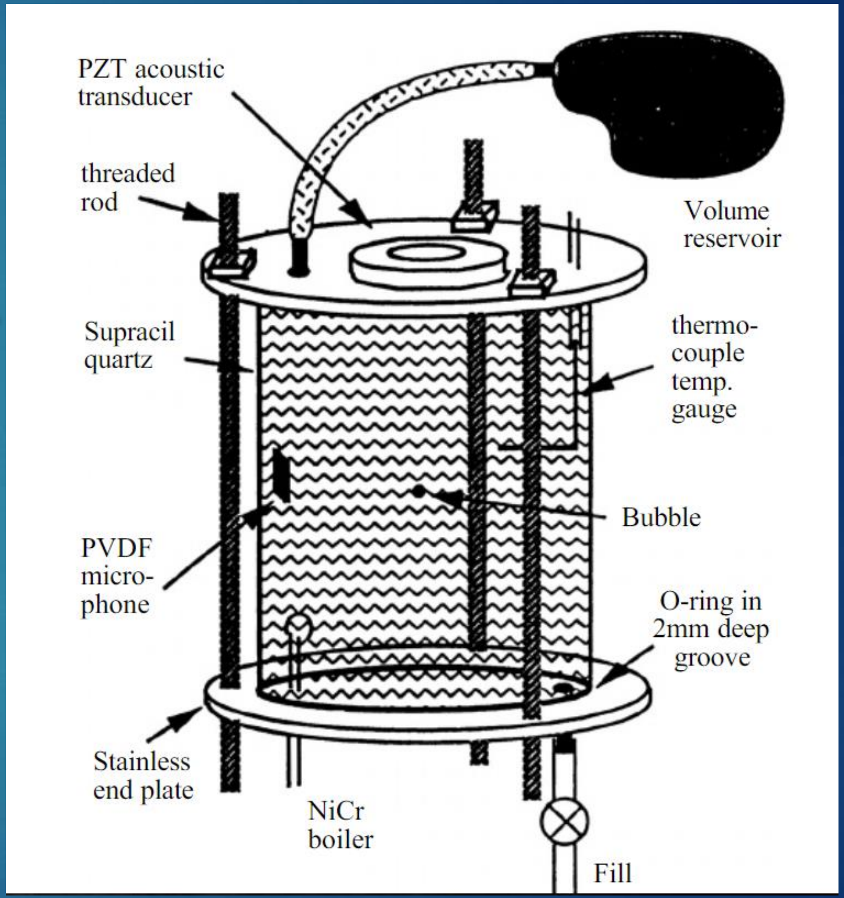
Microgravity Experiment Design

The Resonator

- 3 of 10cmx10cm units
- Central is the resonator
  - Use of a cylindrical resonator



  - Side units for measurement apparatus and experiment circuit



(Young, 2005)

Single Bubble Sonoluminescence

Typical Experiment

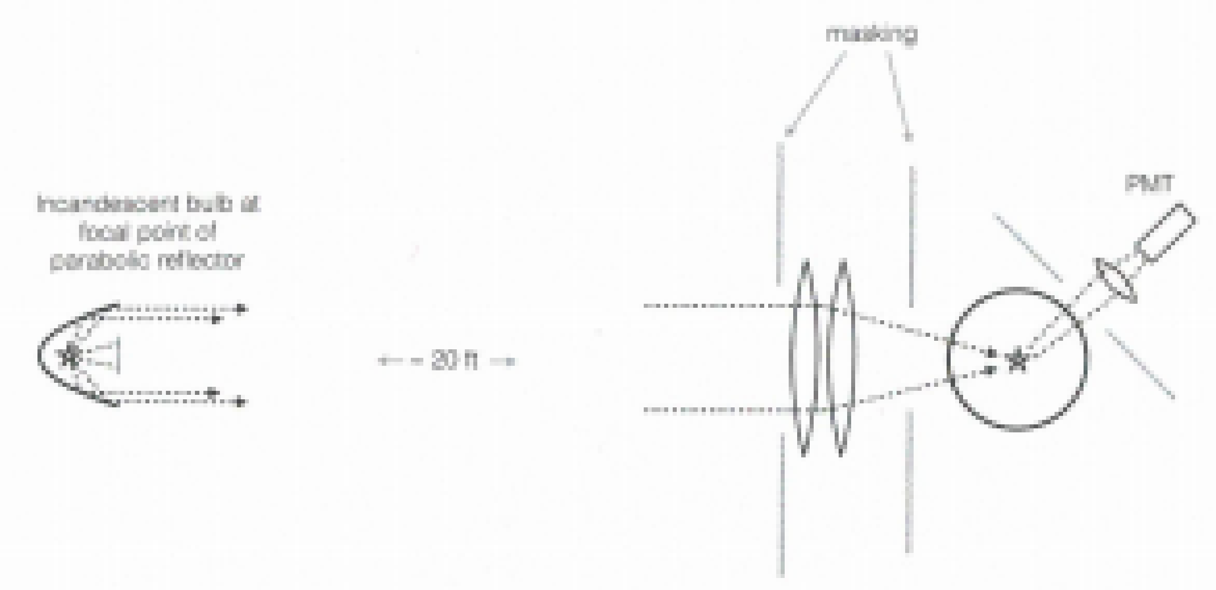
- Equipment:
  - Resonator
  - Piezoelectric transducers
  - Variable inductor
  - Amplifier
  - Function Generator
  - Oscilloscope

Equipment	Typical Value	
Flask	100ml	
PZT	2nF	
Variable Ind	30mH	
Amplifier	40W	

Single Bubble Sonoluminescence

Measurement

- Mie scattering



Single Bubble Sonoluminescence

Rayleigh-Plesset-Keller equation

$$\left(1+\frac{1}{c}\dot{R}\right)\left(P_{gas}-P_0-P_d(t)\right)+\frac{R}{c}\left(\dot{P}_{gas}-\dot{P}_d\right)-4\eta\frac{\dot{R}}{R}-2\frac{\sigma}{R}.$$

Microgravity Experiment Design

Analysis

- Closed system
  - Regulate gas content
  - Potential for higher survivability
- Raspberry Pi allows further automation
  - Feedback from circuit and visual detection
- Include measurement apparatus
  - Measure radius- Mie Scattering
  - Intensity- Photometer