Curvature Dependent Spiral Frequencies of Belousov–Zhabotinsky Waves

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Overview

Belousov-Zhabotinsky (BZ) waves are used in two-dimensional cells to create spirals. A paper by Vladimir Zykov theorized that these spirals have a frequency which depended upon the gaussian curvature of the system. Using an acrylic mold with thirteen hemisphere curvatures, the spirals frequencies were compared. To compare to theory, a ratio of curvature wave speed to planar wave speed, was generated in two ways: local curvatures and average of all curvatures. The results disagree with theory, but further testing is required to draw definitive conclusion.

Theory

Belousov-Zhabotinsky waves are a form of excitable waves.

- **Light Sensitive** – When a light is applied to the system, it excites causing the waves to erase.
- **2D Cell** – If a species is placed into a two-dimensional cell, chemical waves form [1].
- **Spiral Formation** – Ends of waves curl into themselves creating a spiral on the medium [2].

Fig. 1: Example of several BZ waves and spirals propagating in a Petri dish [3].

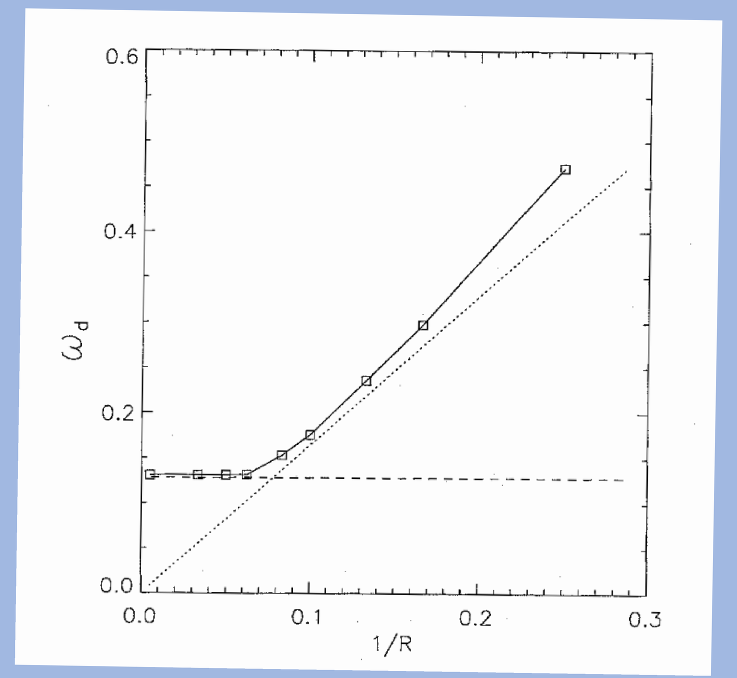

Fig. 2: A graph created by Zykov by combining the small and large radii cases [4].

A 1986 paper by Vladimir Zykov broke spiral frequency onto a curvature into two equations:

- **Small Radii**
  - $\omega_s = \kappa_s(p)V_0\frac{1}{R}$
- **Large Radii**
  - $\omega_L^2 = \omega_0^2 + (1-p)^2V_0^2\frac{1}{R^2}$

Placing this onto a graph shows that at smaller radii (larger curvature), the relationship is more linearly defined, whereas at large radii (smaller curvature) the relationship is quadratically defined.

Occasionally the light sensitive nature is manipulated to produce waves by shining a light on a wave, causing the resultant ends to curve onto themselves [4].

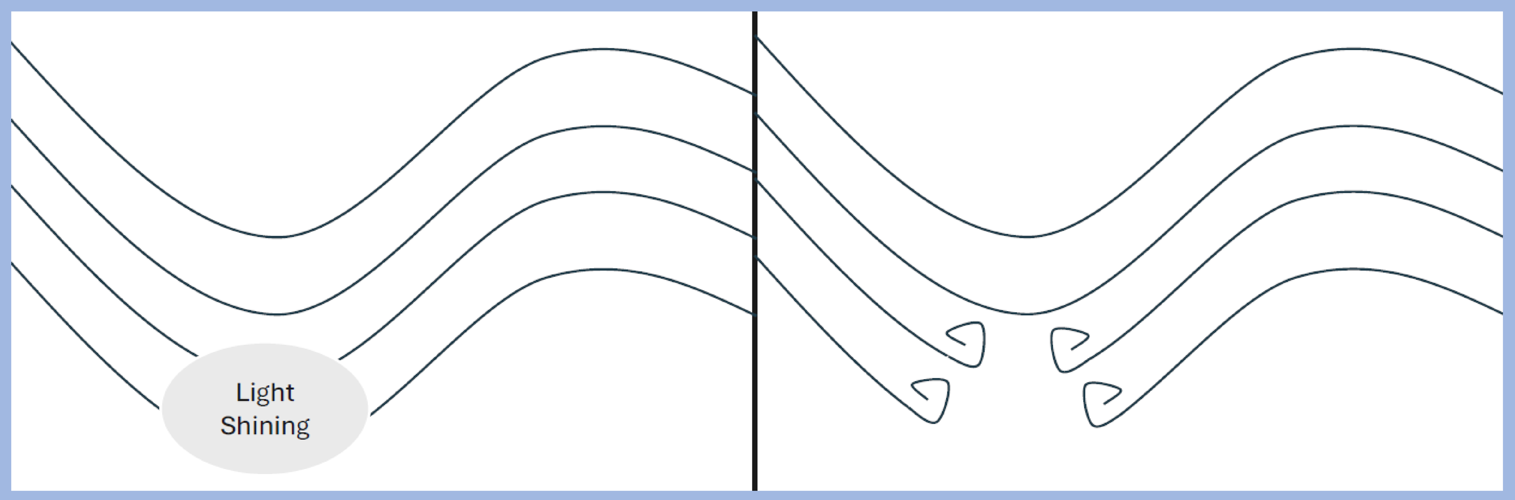

Fig. 3: An example of waves being erased to produce desired spirals. Light is applied and the wave removes itself, producing end point spirals.

To measure this, we define a ratio ***Q*** which is the ratio of frequency on each curvature (ω_G) over the planar frequency (ω_0):

$$Q = \frac{\omega_G}{\omega_0}.$$

The value of Q was calculated using two methods, each changing how the planar frequency was measured:

- **Method 1** – For each Gaussian frequency, the nearest planar spiral was used for comparison.
- **Method 2** – For run one value of planar frequency was calculated using the average of all frequencies.

Methods

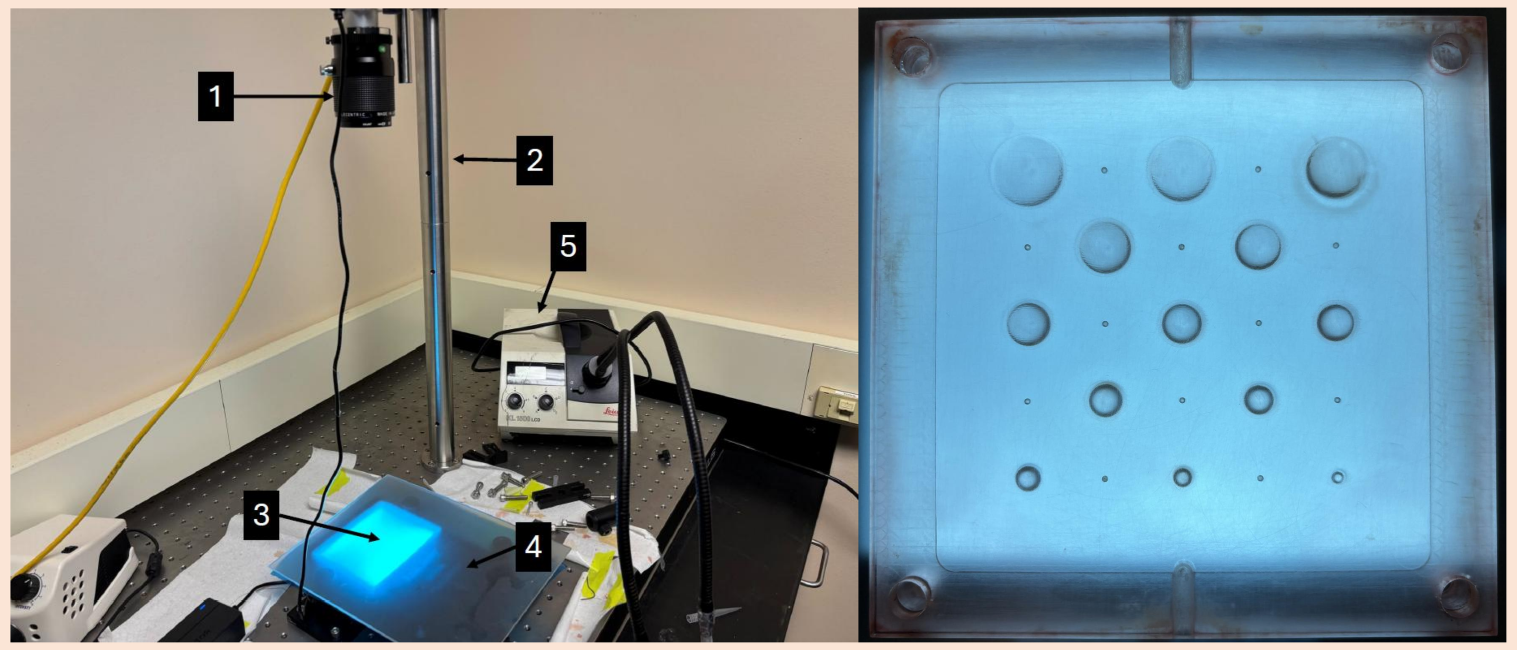

Fig. 4: The imaging setup and mold. The imaging setup is made up of 1) A camera. 2) An arm to adjust the cameras height and angle. 3) A light. 4) A glass platform for imaging. 5) A box which produced a light which allowed wave erasure. **Right:** The curvature mold.

The imaging setup had the mold [5] placed upon the glass platform:

- Images were taken and saved at a regular frequency.
- Solution was prepared and loaded into the curvature mold for imaging.
- Several spirals could be seen per image.

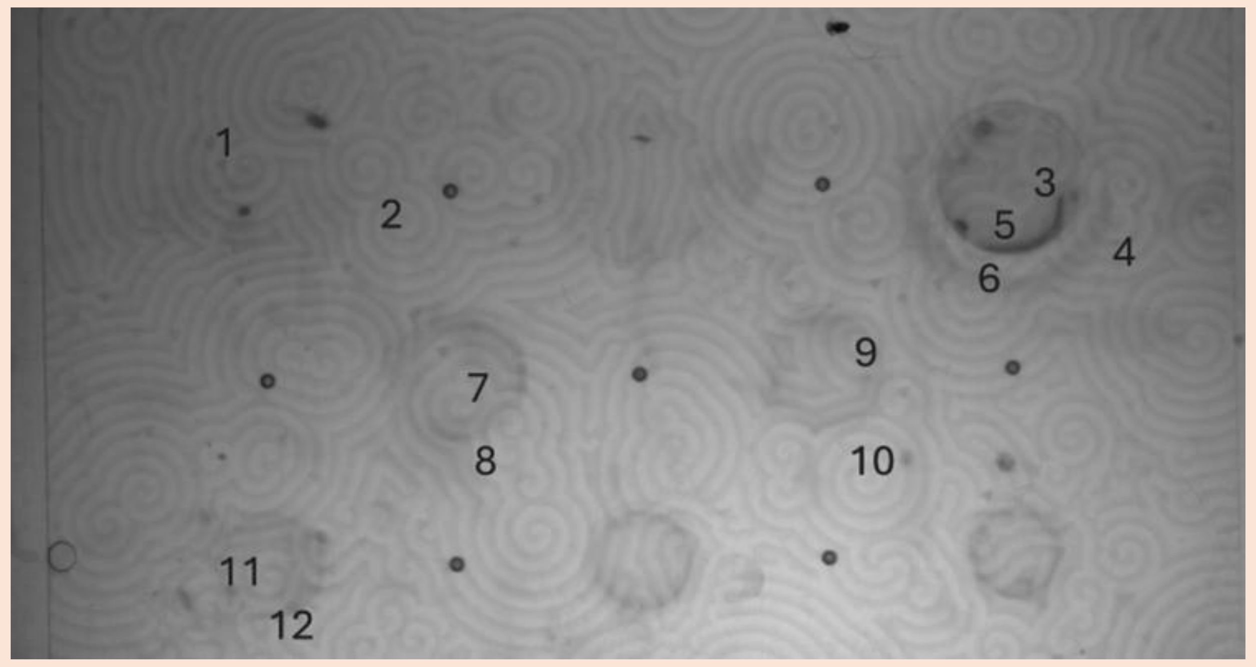

Fig. 5: Image from a run which has had each spiral labeled for reference.

Results

Images had spots measured for the light intensity to get the frequency of waves. For each spiral, two points were measured:

- Where the spiral began.
- Where the spiral ended.

This was necessary due to spiral drift- a process by which spirals move away from a perfectly circular path into a more curved, straight or divergent one.

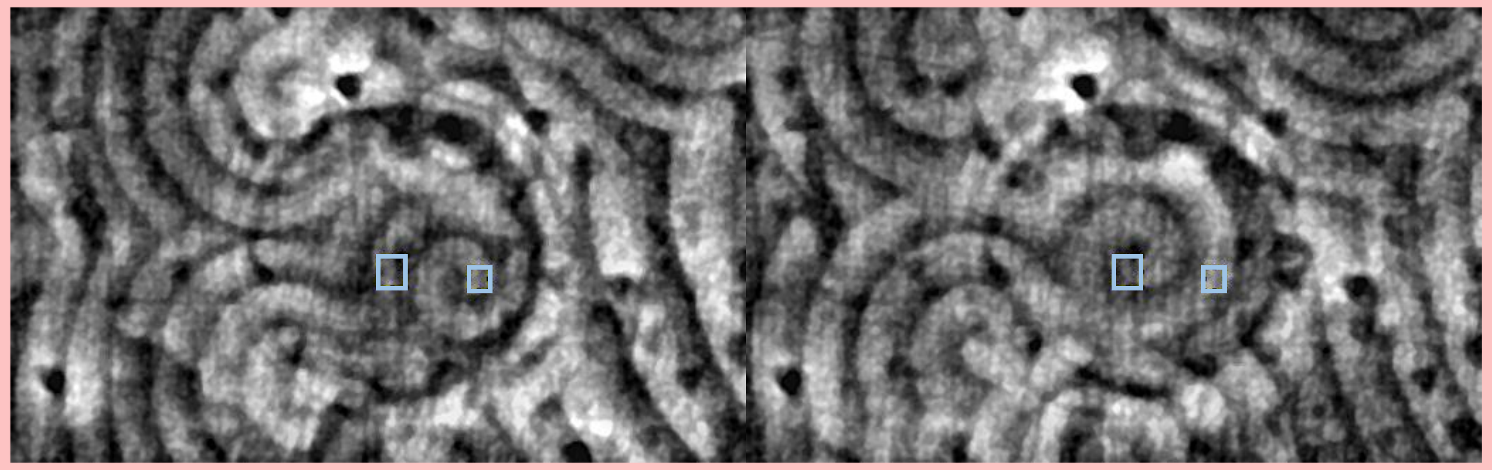

Fig. 6: An image after editing showing spots used to measure. **Left** The image at the earlier image. **Right** The image at the last image taken.

The same start and end points were then used to measure and create intensity plots; these plots allowed the creation of Fourier plots of frequency.

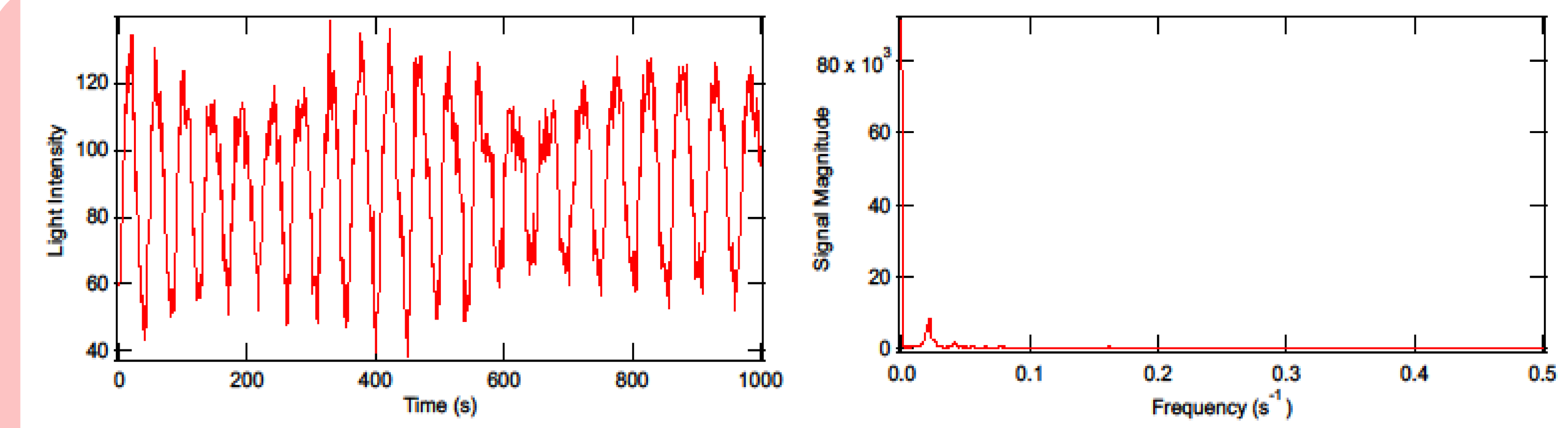

Fig. 7: **Left** Intensity plot for a specific point. **Right** The resulting Fourier transformation plot of magnitudes. The magnitudes were used as strength values to weight each frequency.

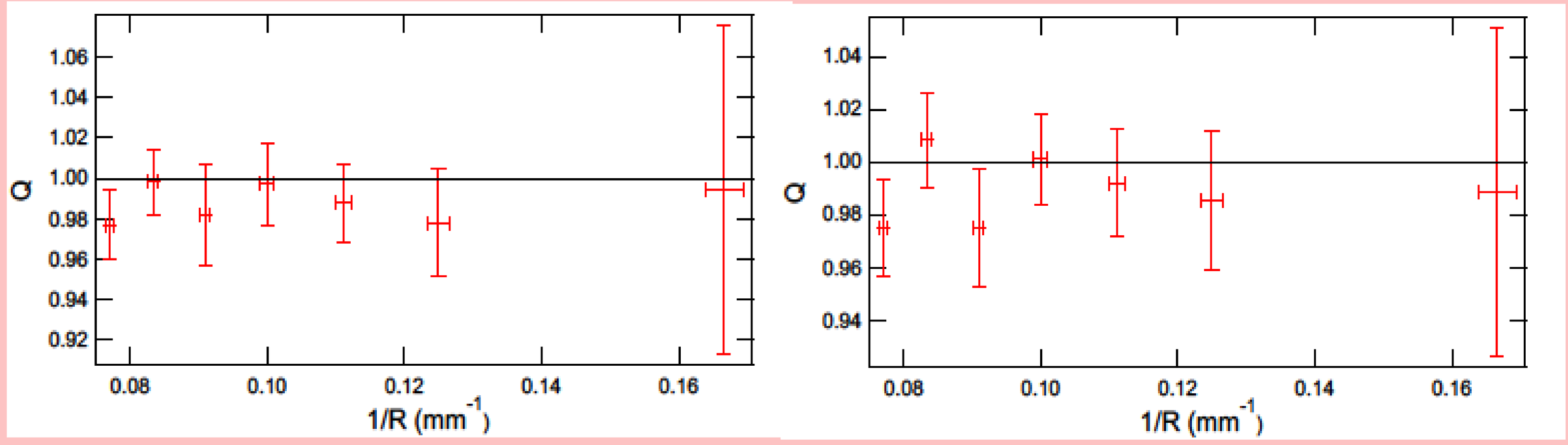

Fig. 8: Graphs from each of the methods for measuring Q. Both graphs have a solid line where one is. **Left:** Method one. **Right:** Method two.

The current model suggests that values below 1 should be impossible, yet each graph contains at least one value below one. This could be caused by:

- Divergence from theory
- Lens affect from the light
- Other curvature types.

Further research must be done to draw definite conclusions.

Acknowledgements

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References

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