CHEMICAL EXPERIMENT

GOLDBACH BRIDGE THEOREM VERIFICATION

Belousov-Zhabotinsky (BZ) Reaction Implementation

Prime Number Synchronization in Chemical Oscillators

Complete Step-by-Step Guide

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Contents

1 EXPERIMENT OVERVIEW

1.1 Scientific Goal

To experimentally verify the Goldbach Bridge Theorem using chemical oscillators (Belousov-Zhabotinsky reactions).

Key Verification Points:

- Demonstrate prime number synchronization
- Measure critical coupling strength κ_c
- Validate scaling law $\kappa_c \cdot \Gamma(N) = 2.539 \cdot N^{0.9327}$

1.2 Chemical Principle

Belousov-Zhabotinsky (BZ) reaction is an oscillating chemical reaction that shows periodic color changes between red and blue due to redox reactions.

Chemical Oscillators for N=30:

- 10 BZ reactors (one for each prime ≤ 30)
- Different oscillation periods: $T(p) = 10\text{s} \times \frac{\ln(p)}{\ln(2)}$
- Goldbach connections through shared chemical mediators

1.3 Expected Visual Results:

Low κ (Weak coupling):

- Each dish oscillates independently
- Random color patterns

Critical κ ($\kappa_c \approx 2 - 5$):

- Goldbach pairs synchronize: 7-23, 11-19, 13-17
- Paired dishes change color simultaneously

High κ (Strong coupling):

- All 10 dishes synchronize
- Unified color changes

2 MATERIALS & PREPARATION

2.1 Chemical Shopping List:

Chemical	Amount	Cost(€)
Sodium Bromate (NaBrO)	50g	15.00
Malonic Acid (CH(COOH))	100g	10.00
Sulfuric Acid (HSO) 0.5M	1L	5.00
Ferroin Indicator	100ml	8.00
Cerium(III) Sulfate	25g	12.00
Bromoacetic Acid	25g	15.00
Potassium Bromide (KBr)	50g	8.00
Potassium Iodide (KI)	50g	8.00

Iron(II) Sulfate (FeSO)	50g	10.00
SUBTOTAL (Chemicals)		**91.00€**
10 Petri Dishes (100mm)	10	5.00
Filter Paper Strips	1 pack	3.00
Graduated Cylinders	Set	15.00
Pipettes & Droppers	Set	10.00
Lab Coat, Gloves, Goggles	Set	20.00
TOTAL ESTIMATED COST		**144.00€**

2.2 Solution Preparation:

Stock Solution A (Oxidizer):

1. Dissolve 15g NaBrO in 250ml distilled water
2. Add 10ml concentrated HSO to 240ml water
3. Mix both solutions carefully

Stock Solution B (Reductant):

1. Dissolve 8g malonic acid in 250ml distilled water

Stock Solution C (Indicator):

1. Use ready-made 0.025M ferroin solution
2. Or prepare: 1.5g phenanthroline + 0.7g FeSO in 100ml water

2.3 Period Modifiers:

To create different oscillation periods for primes:

Fast Oscillators (Small primes):

- Add Ce^3/Ce catalyst (0.1M solution)

Slow Oscillators (Large primes):

- Add bromoacetic acid inhibitor (0.05M solution)

2.4 Target periods for N=30:

Prime	Period	Color Code
2	10.0s	Bright Red
3	15.8s	Orange
5	23.1s	Yellow
7	28.1s	Green
11	36.9s	Blue
13	41.2s	Purple
17	48.6s	Pink
19	51.3s	Brown
23	56.8s	Gray
29	64.7s	Black

3 EXPERIMENTAL PROCEDURE

3.1 Day 1: Chemical Preparation (2-3 hours)

Step 1: Prepare All Solutions

1. Prepare Stock Solution A, B, C as described
2. Prepare mediator solutions:
   - Bromide mediator: 0.1M KBr solution
   - Iodine mediator: 0.1M KI solution
   - Iron mediator: 0.1M FeSO solution
3. Prepare period modifiers:
   - Catalyst: 0.1M Ce^3 solution
   - Inhibitor: 0.05M bromoacetic acid

Step 2: Label Petri Dishes Label 10 dishes with prime numbers: 2, 3, 5, 7, 11, 13, 17, 19, 23, 29 Add color dots according to color code.

Step 3: Prepare Individual Oscillators For each prime p:

1. Add 20ml Solution A to dish
2. Add 10ml Solution B
3. Add 2ml Solution C (ferroin)
4. Add period modifier:
   - Small primes: Add 0.5ml catalyst
   - Large primes: Add 0.5ml inhibitor

3.2 Day 2: Experimental Setup (1-2 hours)

Step 1: Arrange Dishes

1. Arrange in circular pattern with 30cm diameter
2. Place on white background for better contrast

Step 2: Set Up Recording

- Camera on tripod directly above
- White lighting from sides
- Record at 30 fps minimum
- Include timestamp in video

Step 3: Initial Observation Observe without connections ($\kappa = 0$):

- Each dish should oscillate independently
- Periods should differ according to primes
- Record baseline oscillations for 10 minutes

3.3 Goldbach Connections

Connection Method: Filter Paper Bridges

1. Cut filter paper into 1cm × 5cm strips
2. Soak each strip in specific mediator:
   - 7-23 connection: Bromide mediator
   - 11-19 connection: Iodine mediator
   - 13-17 connection: Iron mediator
3. Place soaked strips between dishes
4. One end in dish 7, other end in dish 23, etc.

3.4 κ Control Methods

Coupling Strength κ is controlled by:

1. MEDIATOR CONCENTRATION:

- Low κ: Dilute mediator (0.01M)
- Medium κ: Standard (0.1M)
- High κ: Concentrated (0.5M)

2. CONNECTION AREA:

- Thin strips: Weak coupling
- Wide strips: Strong coupling

3. DISTANCE BETWEEN DISHES:

- Far apart: Weak coupling
- Close together: Strong coupling

4 MEASUREMENT & ANALYSIS

4.1 Video Analysis Setup

Required Software:

- Python with OpenCV: For automated analysis
- Tracker Video Analysis: Free physics software
- ImageJ: For manual frame-by-frame analysis

Analysis Procedure:

1. Extract frames from video (every 0.5 seconds)
2. Convert to HSV color space
3. Measure red/blue intensity for each dish
4. Create time series for each oscillator

4.2 Synchronization Detection

Phase Calculation: For each oscillator i at time t:

$$\theta_i(t) = 2\pi \times \frac{t - t_{\text{red}}}{T_i}$$

Where t_{red} is time of last red peak
T_i is oscillation period

Synchronization Parameter r:

$$r(t) = \left| \frac{1}{10} \sum \exp(i\theta_j(t)) \right|$$

- $r \approx 0.3$: No synchronization
- $r \approx 0.7$: Critical synchronization
- $r \approx 0.9$: Full synchronization

4.3 Finding κ_c Experimentally

Procedure:

1. Start with $\kappa = 0$ (no connections)
2. Gradually increase κ:
   - Step 1: Weak connections (thin strips, dilute)
   - Step 2: Medium connections
   - Step 3: Strong connections (wide strips, concentrated)
3. For each κ value:
   - Record video for 5 minutes
   - Calculate average r
   - Note visual synchronization

4.4 Expected Results for N=30:

κ Range	Expected r	Visual Observation
$\kappa < 1.0$	$r < 0.3$	Chaotic, independent
$\kappa = 2.0 - 3.0$	$r > 0.7$	Goldbach pairs sync
$\kappa > 4.0$	$r > 0.9$	All dishes sync

Theoretical scaling verification: $\kappa_c(\text{exp}) \times \Gamma(30)$ should be close to 77.2
Acceptable error: ±30% for first experiment

4.5 Data Recording Template:

Test	κ value	Mediator	r measured	Sync State
1	0.0	None	0.25 ± 0.05	No
2	1.5	Dilute	0.45 ± 0.07	No
3	2.5	Normal	0.75 ± 0.06	Yes (pairs)
4	3.5	Conc.	0.85 ± 0.04	Yes (all)
5	5.0	Conc.+	0.92 ± 0.03	Yes (all)

5 SAFETY & TROUBLESHOOTING

5.1 Safety Protocol (MANDATORY)

Personal Protective Equipment (PPE):

- Lab coat (mandatory)
- Safety goggles (mandatory)
- Nitrile gloves (mandatory)
- Closed-toe shoes

Chemical Handling:

- Work in well-ventilated area
- No eating/drinking in lab
- Wash hands after handling chemicals
- Have eyewash station accessible

Acid Safety:

- Always add acid to water, NOT water to acid
- Use dilute sulfuric acid (0.5M) when possible
- Neutralize spills with baking soda

Waste Disposal:

- Collect all chemical waste separately
- Neutralize acidic waste before disposal
- Follow local regulations

5.2 Troubleshooting Guide

Problem: No oscillations Solution:

1. Check sulfuric acid concentration (needs 0.5M)
2. Ensure fresh chemicals (malonic acid degrades)
3. Wait 5-10 minutes for oscillations to start

Problem: Oscillations too fast/slow Solution:

1. Adjust catalyst/inhibitor amounts
2. Temperature affects rate (ideal: 20-25°C)
3. Check concentration of all solutions

Problem: Colors not visible Solution:

1. Increase ferroin concentration
2. Use white background
3. Improve lighting

Problem: No synchronization Solution:

1. Increase mediator concentration
2. Use wider filter paper strips
3. Move dishes closer together
4. Ensure proper Goldbach connections

5.3 Common Mistakes to Avoid

1. Using wrong mediator for Goldbach pairs
2. Incorrect prime-to-dish labeling
3. Insufficient video recording time
4. Not allowing system to stabilize
5. Changing multiple variables at once

6 DATA PUBLICATION

6.1 Documenting Results

Essential Materials to Collect: 1. High-quality photos:

- Setup before experiment
- During oscillations
- Synchronized state

2. Video recordings:

- Raw footage (full experiment)
- Highlight clips (synchronization moments)
- Time-lapse (entire experiment)

3. Data files:

- Raw intensity measurements
- Calculated r values
- Phase plots

4. Lab notebook entries:

- Date, time, conditions
- Observations
- Problems encountered

6.2 Scientific Paper Outline

Title: Experimental Verification of Goldbach Bridge Theorem Using Chemical Oscillators

Abstract (150 words):

- State the theorem
- Describe chemical implementation
- Report κ_c found
- Confirm scaling law

Introduction:

- Goldbach Bridge Theorem
- Previous work
- Chemical oscillator background

Methods:

- Detailed experimental setup
- Chemical preparations
- Measurement techniques

Results:

- κ vs r curves
- Video analysis results
- Comparison with theory

Discussion:

- Implications for arithmetic physics
- Limitations
- Future work

Conclusion:

- Summary of findings
- Confirmation of theorem

References:

- Cite original theorem paper
- Cite BZ reaction papers

Supplementary Materials:

- Video files
- Raw data
- Detailed protocols

6.3 Presentation Tips

Conference Presentation (15 minutes):

- 2 min: Introduction & problem
- 3 min: Theoretical background
- 5 min: Experimental method
- 3 min: Results
- 2 min: Conclusion

Poster Presentation:

- Left: Theory & background
- Center: Experimental setup
- Right: Results & conclusion
- Bottom: References & acknowledgments

Social Media Sharing:

- YouTube: Full experiment video
- Twitter: Key findings with #GoldbachBridge #Chemistry
- ResearchGate: Full paper
- GitHub: Analysis code

7 BULGARIAN VERSION

7.1 Khimichen eksperiment za mosta na Goldbakh

1. Tsel na eksperimenta: Eksperimentalno dokazvane na teoremata za mosta na Goldbakh chrez khimichni ostsilyatori (reaktsiya na Belousov-Zhabotinski).

2. Neobkhodimi materiali:

Khimikal	**Kolichestvo**	**Tsena(lv)**
Natriev bromat (NaBrO)	50g	30.00
Malonova kiselina	100g	20.00
Syarna kiselina (0.5M)	1L	10.00
Feroin indikator	100ml	16.00
Tseriy(III) sulfat	25g	24.00
Bromootsetna kiselina	25g	30.00
Kaliev bromid (KBr)	50g	16.00
Kaliev yodid (KI)	50g	16.00
Zhelyazo(II) sulfat (FeSO)	50g	20.00
OBSHTO KHIMIKALI		**182.00lv**
10 chashki Petri (100mm)	10	10.00
Filtur khartieni lenti	1 opak.	6.00
Menzuri i tsilindri	Komplekt	30.00
Pipetki i kapkomeri	Komplekt	20.00
Laboratorno obleklo	Komplekt	40.00
OBSHTA PRIBLIZITELNA TSENA		**278.00lv**

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3. Prosti chisla za N=30: 2, 3, 5, 7, 11, 13, 17, 19, 23, 29
Goldbach dvoiki:

- $7 + 23 = 30$
- $11 + 19 = 30$
- $13 + 17 = 30$

4. Periodi na ostsilyatsii: $T(p) = 10\text{s} \times \frac{\ln(p)}{\ln(2)}$
Primeri:

- $p = 2 \rightarrow T = 10.0\text{s}$ (yarko cherveno)
- $p = 3 \rightarrow T = 15.8\text{s}$ (oranzhevo)
- $p = 5 \rightarrow T = 23.1\text{s}$ (zhelto)
- $p = 29 \rightarrow T = 64.7\text{s}$ (cherno)

5. Goldbach vrazki chrez mediator:

- 7-23: Bromidni yoni (Br/BrO)
- 11-19: Yod (I/I)
- 13-17: Zhelyazo (Fe^{2}/Fe^{3})

6. Ochakvani rezultati:

- **Pri slabo svarzvane:** Vsichki chashki ostsiliirat nezavisimo
- **Pri kritichno svarzvane:** Goldbach dvoiki se sinkhronizirat
- **Pri silno svarzvane:** Vsichki 10 chashki sinkhronizirani

8 CLOSING PAGE

8.1 EXPERIMENT COMPLETE GUIDE

This PDF contains all information needed to conduct the chemical experiment for Goldbach Bridge Theorem verification. Follow the step-by-step instructions carefully for successful results.
KEY POINTS:

- Safety first! Always use PPE
- Document everything
- Be patient - chemical reactions take time
- Share your results

GOOD LUCK!
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SCIENTIFIC DISCOVERY AWAITS!