Irreversibility of processes and the Loschmidt paradox

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1. Introduction and Motivation

Everyday phenomena, like the dispersal of an ink droplet in water or the temperature equilibrium achieved between two touching bodies, have naturally developed our sense of the arrow of time. Indeed, it has become so natural that one would immediately be able to tell that a video of ink dispersion is fake when the video is reversed. Stephen Hawking identified three types of arrows of time: psychological, thermodynamic, and cosmological. In this work, I am examining the thermodynamic arrow, which is the direction of entropy increase. The aforementioned phenomena are governed by the Second Law of Thermodynamics, which establishes the concept of entropy and states that it cannot decrease at any given time. Hence natural processes can only happen in one direction meaning that they are irreversible. The Loschmidt-paradox, posed by Josef Loschmidt in the 19th century, presents the question of whether reversible macrosystems which are time-symmetric in the microstate exist. Studying the arrow of time shows how our knowledge in the irreversible world is limited by only knowing one way.

In this study, I am looking for physical systems, where the so-called Loschmidt-echo is realized. The Loschmidt-echo demonstrates a process where the system after an original dephasing returns more or less to the initial state. The existence of the Loschmidt echo can be expected in systems where the loss of information is partial or slow. With the use of a ”trick”, the system can be returned to the almost identical original state, thus seemingly reversing the arrow of time. Several systems, in which Loschmidt-echo can be realized, already exist: the sliding of balls down the tautochrone curve, the Newton's cradle, the magnetic resonance spin-echo, or the herein-studied laminar flow of a high viscosity material.

For the study, I studied the laminar flow of cooled glycerol between two co-axial plexiglass cylinders, which are coloured with different droplets. This system is known to be able to demonstrate the Loschmidt echo and my task was to reproduce this experiment and identify the optimal experimental conditions. In the experiment, I turned the inner cylinder in a certain (clockwise or anti-clockwise) direction with a constant speed to spread the colours. After a few turns, I turned the cylinder backwards until the droplets returned to their initial position, thus accomplishing the Loschmidt-echo. The flow was modelled with the Taylor-Couette laminar flow equations. Clearly, the presented experiment does not violate the entropy increase as the initial dephasing was reversible, therefore no memory loss occurred.

The aforementioned phenomenon thus obeys the Second Law of Thermodynamics and nicely demonstrates its working, which is often neglected in the high school curriculum. This work aims to provide an example of the Loschmidt-paradox which seemingly refutes the idea of entropy increase but instead, it rather reinforces the validity of the Second Law of Thermodynamics.

2. Theoretical Background

2.1 Second Law of Thermodynamics

2.1.1 Formulations of the Second Law of Thermodynamics

There exist several natural processes, for which we have developed the natural sense of direction of time. However, in principle, the exact opposite of these can happen, yet we never experience them. These phenomena are as follows.

- Two touching bodies with different temperatures always achieve thermal equilibrium. The hot will never get hotter, the cold will never get colder. For example, a cold cup that contains hot coffee will always turn hotter and not colder. (Figure 2)
- The opening hole on an inflated balloon lets the air out and not in.
- A bouncing ball always decreases the level of bounce and does not increase.
- The ink droplet in water always disperses and does not come together. (Figure 1)
- The water left in the cup always evaporates, but the vapor in the air never comes back to the cup.

Figure 1

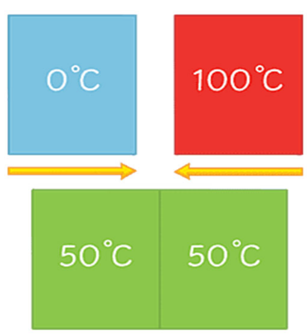

Figure 2

There are several statements of the Second Law of Thermodynamics (Újsághy, 2013):

- Any spontaneous process will always increase the entropy of the universe or the entropy of an isolated system never decreases.
- No heat engine can have 100% efficiency.
- It is impossible to transfer heat from a cold body to a hot body without the use of an external energy source.

The last statement also introduces the concept of irreversibility, which simply means that natural processes have a certain direction and cannot be reversed. Following that, a process is reversible if it can return to its starting point with no other change in the universe. In this research, we are looking for this kind of reversible system.

2.1.2 Boltzmann's statistical description of the Second Law of Thermodynamics

In 1877, Ludwig Boltzmann suggested a law that establishes a connection between the concept of entropy, which is the amount of disorder of a system, with a statistical description. From a statistical point of view, entropy (S) can be written as the product of the Boltzmann constant and the natural logarithm of the number of microstates (**Ω**).

$$S = k_B \ \ln \Omega$$

This means that the direction of natural processes like the dispersal of ink droplets in water can be understood from a statistical perspective. In this statistical approach, we can say that these processes happen because one microstate among others occurs with the highest probability within the macrostate. However, this does not mean that other microstates can not happen – they can, it is just extremely unlikely. To illustrate this possibility, Steven Weinberg formulated the so-called "infinite-monkey theorem". The theory is that the probability of a dust particle cooling 1 milliKelvin compared to its environment is the same as the probability of infinite monkeys typing one of Shakespeare's dramas on typewriters for an infinite amount of time. Upon doing the calculation, we find that the probabilities are indeed similar.

2.1.3 The cooling of a dust particle and the Infinite Monkey Theorem

In this calculation, we are curious about the probability of a dust particle with a mass of $m = 1$ microgram, spontaneously cooling $\Delta T = 1$ miliKelvin compared to its environment. Because of the statistical understanding of entropy, we know there is a finite probability. The heat transferred from the dust is $Q = c * m * \Delta T = 1nJ$ (where $c = \frac{kJ}{kg*K}$). The entropy change $\Delta S = -\frac{Q}{299.999} + \frac{Q}{300} = -1 * 10^{-17} \frac{J}{K}$. The entropy (S) from Boltzmann's entropy formula is $S = k_B \ln \Omega$, where k_B is the Boltzmann constant ($1.38 * 10^{-23} \frac{J}{K}$) and Ω is the number of possible microstates. For smaller entropies, there are fewer microstates, in this case around $e^{700\,000} \approx 10^{300\,000}$ less. Hence, the probability of 1 miliKelvin cooling of a dust particle is one to this enormous number.

To illustrate this finite probability, the aforementioned Steven Weinberg established the infinite monkey theorem which has a similar scale of probability. In his book, 'The First Three Minutes', he tried to illustrate this infinite monkey and typewriter idea. The theory is the following: given infinite monkeys and each of them can randomly press a key on their designated typewriter for a long time, one of them will successfully type Shakespeare's longest drama. Although we know that the probability is extremely small, it is finite.

Shakespeare's longest drama, Hamlet, has around 130 000 characters if we dismiss punctuation and capitalization. The English alphabet has 26 characters, hence the probability to have the first letter right is 1 to 26. For the first two character this probability is 1 to 676. As for the first two lines, which have 50 characters, the probability to have it rights is 1 to $26^{50} \approx 10^{71}$.

As follows, the chance to have the whole drama right is 1 to $26^{130\,000} \approx 10^{184\,000}$. However, this value is still significantly smaller than that of the dust particle. Suppose we have one monkey to type on one typewriter for the time of the Universe to date (approximately $4 * 10^{17}\ seconds$), the resulting character series is $4 * 10^{17}$ characters. To find the probability of the length of the drama, 130 000 characters in this we can use the binomial distribution.

2.2 Microscopic reversibility of processes and the principle of detailed balance

The principle of microscopic reversibility: The mechanism of a reversible reaction is exactly the same (but reversed) for both the forward and backwards version of the reaction. This mechanism exists because the microscopic motions are symmetric with respect to time. So in theory, if we substitute t with $-t$ in a classical mechanics equation, it does not invalidate the equation. An easy demonstration can be found below, where the collisions of the Newton's cradle satisfy the laws of classical mechanics. Moreover, when the system is in equilibrium the forward rate of the molecular process has to be equal to the reverse rate of the same process. In a macroscopic scale, this means that each forward step equals the reverse step; this is the principle of detailed balance. (Alberty, 2004)

2.2.1 Elastic collision

An elastic collision is a phenomenon where the arrow of time might not be clearly observed because one would not be able to tell if the direction of the process is reversed. In a perfectly elastic collision, where the kinetic energy of objects does not convert into other forms of energy such as heat, the direction in which the process is happening is not visible to the naked eye. However, perfectly elastic collisions do not exist and in elastic collisions, some energy will always be converted to heat due to friction. In an elastic collision momentum and kinetic energy of the objects should be conserved

$$m_1 v_1 + m_2 v_2 = m_1 v'_1 + m_2 v'_2$$

Conservation of momentum

$$\frac{1}{2} m_1 {v_1}^2 + \frac{1}{2} m_2 {v_2}^2 = \frac{1}{2} m_1 {v'_1}^2 + \frac{1}{2} m_2 {v'_2}^2$$

Conservation of kinetic energy

After solving these equations, we get the following parametric equation:

$$v'_1 = \frac{m_1 - m_2}{m_1 + m_2}\, v_1 + \frac{2m_2}{m_1 + m_2}\, v_2$$

$$v'_2 = \frac{2m_1}{m_1 + m_2}\, v_1 + \frac{m_2 - m_1}{m_1 + m_2}\, v_2$$

Imagine the following scenario: two objects with identical masses m1 and m2, but different velocities, v1 and v2, are collided with each other.

$$v_1 = v'_2 \;\; and \;\; v_2 = v'_1$$

Upon collision, which is assumed to be elastic, their velocity simply exchanges. Hence, the exchange of velocities is unnoticeable. (Raymond A. Serway, 2014)

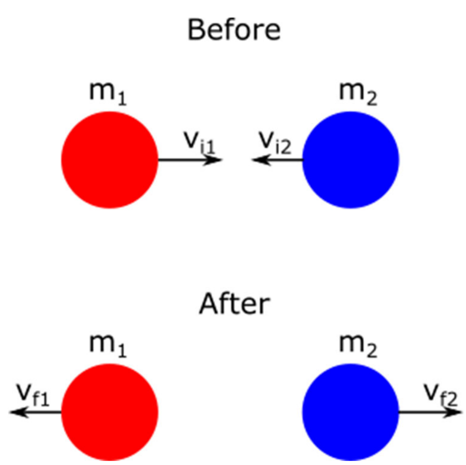

Figure 3

2.2.2 The Newton's cradle

Similar elastic collisions occur in Newton's cradle, but after some time, the balls slow down and there is no more movement because the kinetic energy is turned into potential energy. Hence, the 'perfect' Newton's cradle does not exist since it will always stop. Furthermore, the direction of the oscillation will always be observable with the use of a thermal camera.

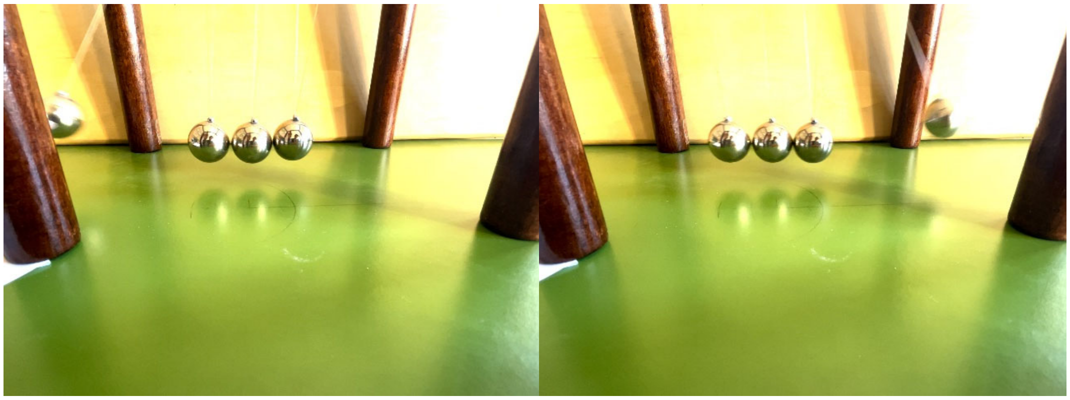

Figure 4

For instance, looking only at the pictures above (Figure 4), one would not be able to tell which picture was taken first.

2.3 The Loschmidt paradox and the Loschmidt echo

The Boltzmann statistical description of the equilibrium of states and the increase of entropy, as well as the relation between the number of microstates and the entropy, has proven to be correct. Much as it has turned out to be correct, it generated one of the most interesting intellectual debates of the 19th century. Josef Loschmidt suggested that the Boltzmann hypothesis contradicts the reversibility of the fundamental processes. E.g. the aforementioned elastic collision is completely symmetric in time, therefore the arrow of time is not distinguished, and any process could happen reversibly. Similarly, the Newton's cradle also demonstrates such a process, which is (almost) reversible. It is now understood that the Boltzmann hypothesis is indeed correct for a large number of particles and that the entropy always increases; however, its formal discussion is beyond the scope of this work.

The suggestion of Loschmidt entered the history of science as the Loschmidt paradox: although the microscopic processes are fully reversible on the ensemble scale, we only observe irreversibility. The paradox has also suggested that there may exist systems where a time-symmetric state can be at least partially realized, such a system is called to display a Loschmidt echo.

We expect the existence of the Loschmidt echo in systems, where an initial reversible decoherence (or dephasing) occurs, which is however not accompanied by memory loss. Therefore it can be at least partially recovered. This seemingly violates the Second Law of Thermodynamics, however, it turns out that the initial dephasing is not accompanied by an increase in entropy, therefore the reversal does not correspond to a decrease in entropy. A few systems are known to display the Loschmidt echo:

- The spin echo in magnetic resonance (Hahn, 1950) and its related version the neutron spin-echo developed by Ferenc Mezei (Mezei, 1979)

- The Newton's cradle. To my knowledge, we suggest herein for the first time that it is a realization of the Loschmidt echo.

- A similar mechanical system is balls sliding on a so-called tautochrone curve, also suggested herein as a demonstration of the Loschmidt echo.

- The circular laminar flow has been also known to demonstrate the Loschmidt echo. I herein study this system in detail. A demonstration of the Loschmidt echo using this effect is available herein (Univ. New Mex, 2007).

Additionally, the so-called chemical waves of the Belousov–Zhabotinsky (BZ) reaction are also known to be a form of Loschmidt echoes

It was my task in this work to demonstrate the Loschmidt echo using the laminar flow and to optimize the required experimental conditions.

2.4 Laminar flow in viscous fluids

2.4.1 The Newton's law of viscosity

Viscosity is a physical property that describes the resistance of a flow. For moving fluids, the viscosity is stated by Newton's law of viscosity. It defines that the shear stress is directly proportional to the rate of shear strain. In other words, the shear stress between adjacent fluid layers is proportional to the velocity gradient between the two layers.

Mathematically speaking,

$$\tau = \mu \frac{du}{dy}$$

where

τ is the shear stress of the fluid

μ is the viscosity

$\frac{du}{dy}$ is the velocity gradient that is parallel to the direction of the shear. (Engrraihan, 2015)

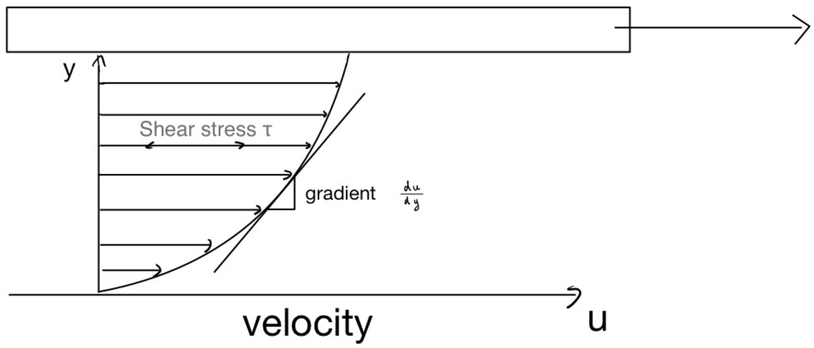

Figure 5

Hence, there exist Newtonian and non-Newtonian fluids which do or do not satisfy the law of viscosity, respectively. For a Newtonian fluid, viscosity is independent of the shear rate. Non-Newtonian fluids do not follow Newton's law and, thus, their viscosity (ratio of shear stress to shear rate) is not constant and is dependent on the shear rate. (Herman F. George, 2013) In our everyday lives, we know several Newtonian fluids like water, honey or glycerol for which viscosity is only dependent on temperature. Glycerol, for instance, decreases in viscosity as the temperature increases (Figure 6). For non-Newtonian fluids like ketchup or eye droplets, viscosity changes when force is acted on it. In fact, there are two classes of non-Newtonian fluids: those which become more viscous under stress (like ketchup and eye droplets) and those which become more rigid under stress (e.g. corn starch and children's toy, the so-called "smart putty"). This property is e.g. very important for eye droplets: upon no eyelid movement, the eye droplets are not very viscous, thus remaining in place. However, for a rapid eyelid closure (or blinking), it has little friction.

TABLE V. VISCOSITY OF AQUEOUS GLYCEROL SOLUTIONS

Glycerol, % Wt.	Temperature, ° C. Viscosity, Centipoises 0	10	20	30	40	50	60	70	80	90
0[a]	1.792	1.308	1.005	0.8007	0.6560	0.5494	0.4688	0.4061	0.3565	0.3165
10	2.44	1.74	1.31	1.03	0.826	0.680	0.575	0.500	...	...
20	3.44	2.41	1.76	1.35	1.07	0.879	0.731	0.635	...	...
30	5.14	3.49	2.50	1.87	1.46	1.16	0.956	0.816	0.690	...
40	8.25	5.37	3.72	2.72	2.07	1.62	1.30	1.09	0.918	0.763
50	14.6	9.01	6.00	4.21	3.10	2.37	1.86	1.53	1.25	1.05
60	29.9	17.4	10.8	7.19	5.08	3.76	2.85	2.29	1.84	1.52
65	45.7	25.3	15.2	9.85	6.80	4.89	3.66	2.91	2.28	1.86
67	55.5	29.9	17.7	11.3	7.73	5.50	4.09	3.23	2.50	2.03
70	76.0	38.8	22.5	14.1	9.40	6.61	4.86	3.78	2.90	2.34
75	132	65.2	35.5	21.2	13.6	9.25	6.61	5.01	3.80	3.00
80	255	116	60.1	33.9	20.8	13.6	9.42	6.94	5.13	4.03
85	540	223	109	58.0	33.5	21.2	14.2	10.0	7.28	5.52
90	1310	498	219	109	60.0	35.5	22.5	15.5	11.0	7.93
91	1590	592	259	126	68.1	39.8	25.1	17.1	11.9	8.62
92	1950	729	310	147	78.3	44.8	28.0	19.0	13.1	9.46
93	2400	860	367	172	89.0	51.5	31.6	21.2	14.4	10.3
94	2930	1040	437	202	105	58.4	35.4	23.6	15.8	11.2
95	3690	1270	523	237	121	67.0	39.9	26.4	17.5	12.4
96	4600	1585	624	281	142	77.8	45.4	29.7	19.6	13.6
97	5770	1950	765	340	166	88.9	51.9	33.6	21.9	15.1
98	7370	2460	939	409	196	104	59.8	38.5	24.8	17.0
99	9420	3090	1150	500	235	122	69.1	43.6	27.8	19.0
100	12070	3900	1412	612	284	142	81.3	50.6	31.9	21.3

[a] Viscosity of water taken from Bingham and Jackson (4).

Figure 6: Viscosity of glycerol at different temperatures (J. B. Segur, 2002)

Honey type	Moisture (%)	Viscosity mPa.s[d]
Artificial	$17.5^{a} \pm 0.002$	8,000

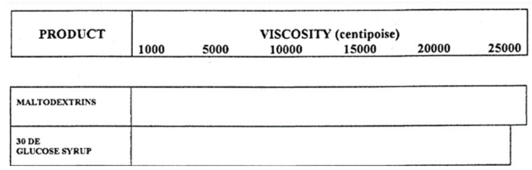

Figure 7: Viscosity of honey and glucose syrup ($1\ mPa.s = 1\ centipoise$) (Brenda Mossel, 2003) (Kearsley, 1995)

In the comparison of the viscosity of the herein studied fluids, glucose syrup had the highest viscosity. However, later in this paper, we see that neither of the high viscosity the glucose syrup nor the low value of honey is optimal for this experiment. As a result, the value of the glycerol proved to be in the middle of the extremes.

2.4.2 The Taylor-Couette flow

Taylor-Couette flow occurs in viscous fluids which are enclosed between two coaxial cylinders, which rotate. In my research, the system was built with plexiglass and the flow was azimuthal. For the description of the flow, I substituted the values in the equation below.

The azimuthal velocity v is given by (Davey, 1962)

$$v = Ar + \frac{B}{r}$$

where A and B are

$$A = \Omega_1 \frac{\mu - \eta^2}{1-\eta^2} \quad B = \Omega_1 R_1^2 \frac{1-\mu}{1-\eta^2}$$

Where μ and η is given by

$$\mu = \frac{\Omega_2}{\Omega_1} \text{ and } \eta = \frac{R_1}{R_2}$$

In this case, the outer cylinder does not rotate, hence $\Omega_2 = 0$, which means that $\mu = 0$ as well. After further substitution and simplification, the equations are

$$A = \Omega_1 \frac{-\eta^2}{1-\eta^2} \text{ and } B = \Omega_1 R_1^2 \frac{1}{1-\eta^2}$$

Since the radius of the outer cylinder (R_2) is larger than that of the inner (R_1),

η is less than 1.

Using this, we get

$$A = \Omega_1 \eta^2 \text{ and } B = \Omega_1 R_1^2$$

For the inner cylinder's radius, R_1 , the equation is

$$-\Omega_1 \eta^2 R_1 + \frac{\Omega_1 R_1^2}{R_1}$$

Since the first part of the addition can be neglected, v for R_1 equals

$$\Omega_1 R_1$$

For the outer radius, R_2,

$$-\Omega_1 \eta^2 R_2 + \frac{\Omega_1 R_1^2}{R_2}$$

This can be written as

$$-\Omega_1 \frac{R_1^2}{R_2} + \frac{\Omega_1 R_1^2}{R_2} = 0$$

Which is true, since the outmost layer does not move.

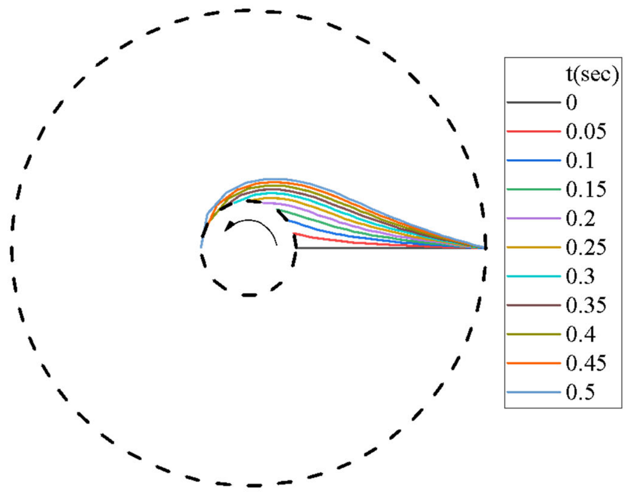

Figure 8

Description: Phase points of Taylor-Couette flow occurring between two coaxial cylinders, demonstrated for an angular frequency $\omega = 2\frac{Rad}{s}$. The two dotted lines show the inner and outer cylinders.

3. Experimental Details

3.1 The experimental setup

For the experiment, the apparatus being constructed was inspired by previous similar existing versions found on the Internet. For the realization of the Loschmidt echo, I used several laboratory equipment. For the base, I glued a 500 ml transparent beaker to a plexiglass in a way that the beaker remained fixed. What is more, two additional screws (around 12 cm long) were screwed into it, providing support for the inner cylinder. The inner cylinder (with around a 3cm diameter) which submerges into the bigger cylinder is also transparent. The inner cylinder also has a crank arm attached to it, which enables turning with precision (Figure 3). These instruments were kindly prepared by Béla Horváth and Márton Hajdú following my design.

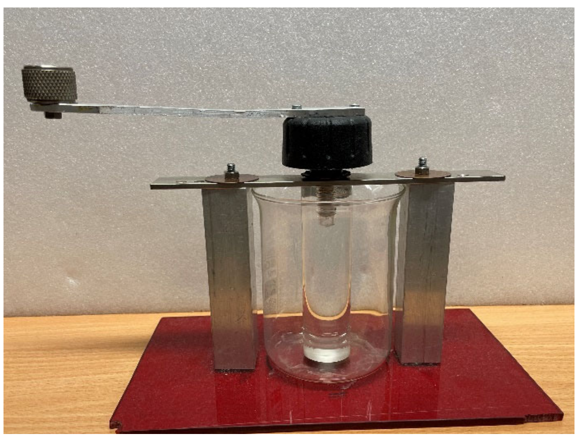

Figure 10

Figure 9

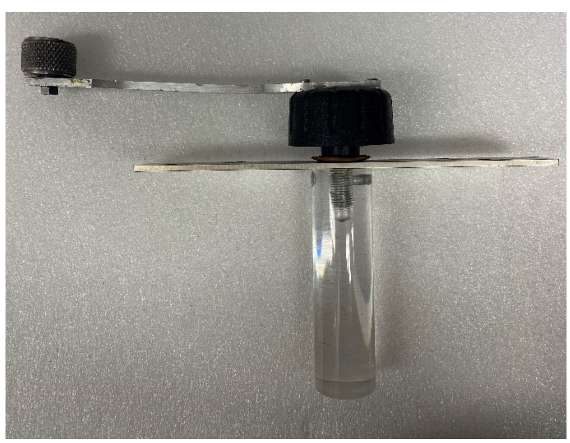

Figure 11

Furthermore, I tried several viscous fluids and food colourings. Due to the demand for high viscosity, only glycerol proved to be viscous enough among several other fluids. The reason for high viscosity is the slower diffusion between the coloured droplets and the surrounding fluid. For perfect condition, I cooled the glycerol to minus 18 Celsius, which further increased its viscosity. As for the better distinction of droplets, I used different colours including blue, green and red. To form drops, I used a rubber-tipped pipette, because the traditional one did not work. Additional equipment were two ventilators, which were implemented to stop the condensation of vapour on the wall of the beaker.

Figure 12

3.2 The experiment

In the experiment, I placed cold (around -18 °C) glycerol in the gap between the two cylinders. Then, I placed three droplets of food colourings with different colours. I recognized that dropping the colourings themselves into the glycerol did not produce meaningful results as the two materials have very different densities. I therefore, coloured a small amount of glycerol prior to the experiment with the food colouring and dropped it into the pure glycerol. After, I started to turn the inner cylinder in one direction (clockwise or anti-clockwise) dispersing the three drops. Next, I turned the same amount of turns backwards to bring the drops back to their initial position, hence demonstrating the Loschmidt-echo.

4. Results and Discussion

4.1 Laminar flow with glucose syrup and honey

Initially, I had three fluids in mind: glycerol, honey and glucose syrup. Although glucose syrup and honey had a similar or higher viscosity than glycerol, they were harder to manipulate due to stickiness.

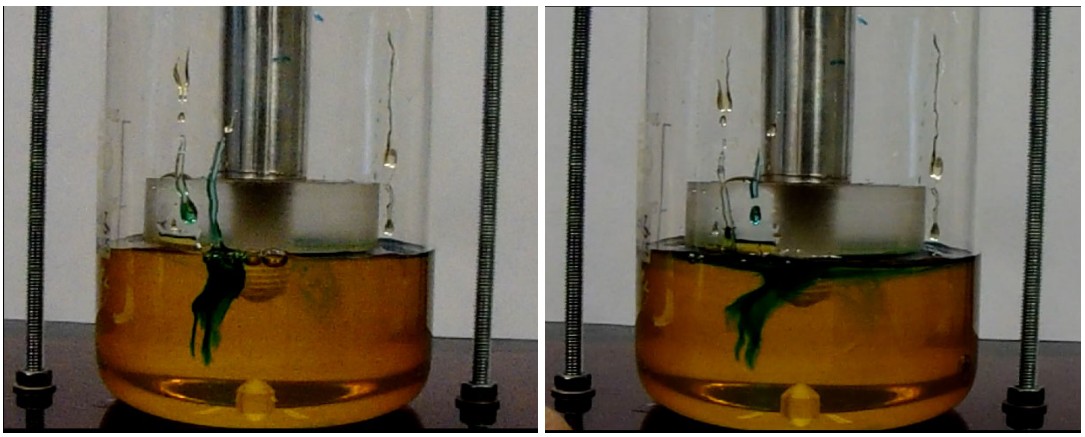

Figure 13: honey

The experiment with honey: beginning and end of the rotations. Notice the difference on the top of the fluid, because the less dense colour ”swam” to the top which also impacted the Loschmidt-echo. (Figure 13)

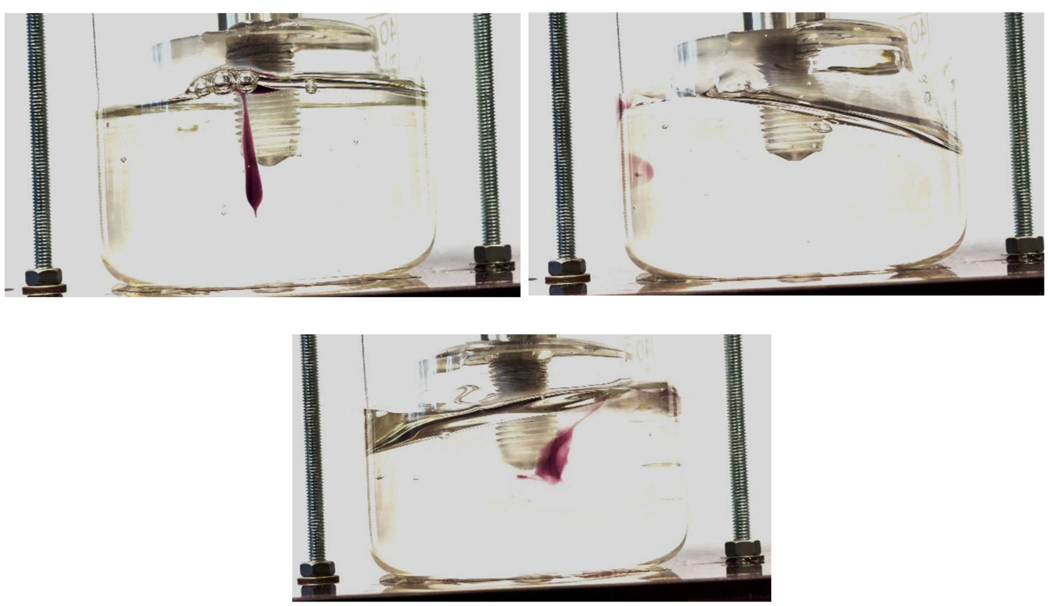

Figure 14: glucose syrup

The rotations done with glucose syrup were unsuccessful because the turning was faster than the response to achieve the transient state. This is the reason for the wave in the second picture, where one side is higher than the other. In theory, if the angular velocity was small enough, Loschmidt-echo could be realized in glucose syrup as well. (Figure 14)

Discussion

The experiment with honey did not yield the desired results, because its viscosity was not high enough. Furthermore, the food colour contained a significant amount of water that diluted the honey. The density of the coloured droplets was much smaller, which resulted in the lifting of the drops to the top of the surface. In the case of glucose syrup, the back-and-forth rotations were hard to carry out because of the high viscosity. The fluid started to ”wave”, which disturbed the laminar flow and made the realization of the Loschmidt-echo impossible. From the two instances, it can be deduced that the viscosity can neither be extremely high nor low.

4.2 Demonstration of the Loschmidt echo with glycerol

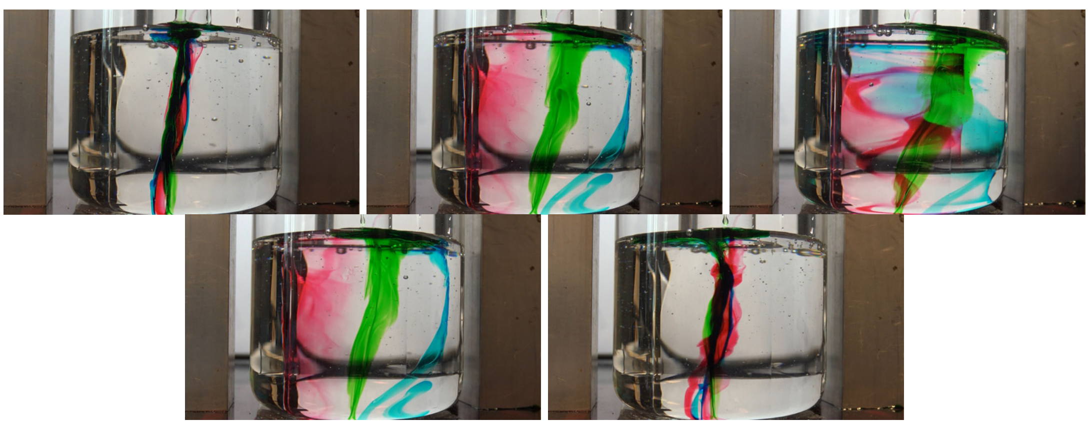

Figure 15: glycerol (two rotations)

In the pictures above, we demonstrated the experiment with three different coloured stripes and two complete turns. The colours are green, blue and red with the green stripe in the outmost layer and the red stripe closest to the rotating, inner cylinder. In the first picture (up-left), the stripes are in the initial position, behind each other. Then, we have one turn (up-middle) and two turns in the anti-clockwise direction (up-right). The lower two pictures represent one and two turns backwards.

I also did the same experiment with three identical coloured droplets beside each other:

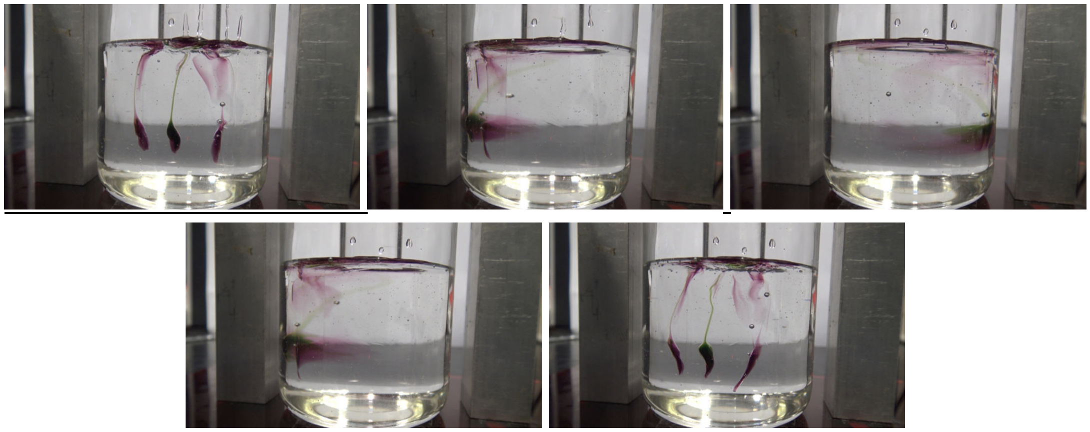

Figure 16: glycerol (two rotations)

Here, the two initial rotations were in clockwise direction, which was followed by two counter-clockwise. The phases from left to right are: the beginning, first rotation, second rotation (middle), first rotation back, and second rotation back.

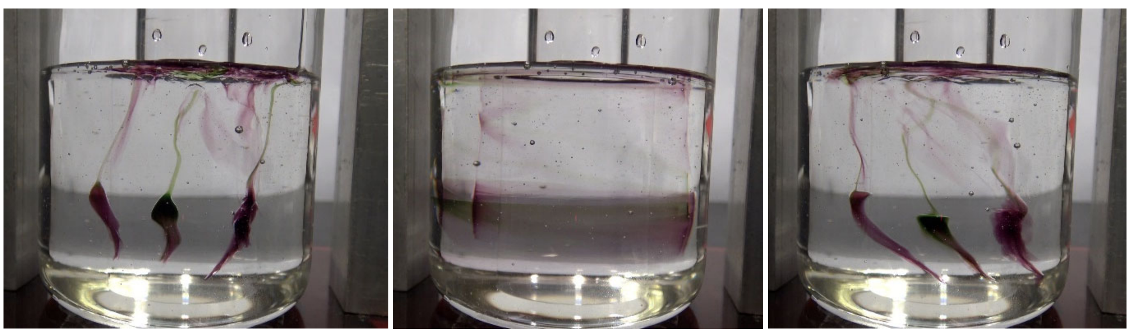

Figure 17: glycerol (three rotations)

I also took videos of the Loschmidt echo experiments which are available herein:

https://drive.google.com/drive/folders/1NX4j4XTcYTArUcngkOtPS9bAesGHU--L?usp=sharing

The temperature of the glycerol is an important factor, as the viscosity decreases for higher temperatures. In the two previous attempts, the glycerol and the droplets were cooled to -18 °C. As the pictures show, the results were much better.

It is also important to point out that the initial direction of the rotation does not matter since the rotations back-wards will always happen in the opposite direction. However, the number of rotations is constrained because the more rotations we do the less likely it will come back to the initial state. In my experience and as the last pictures show, anything more than three turns is unlikely to return intact to the original phase.

I also noticed an interesting effect, which I call transient: when the rotation starts, there is clearly a small period needed for the laminar flow to attain the steady-state flow profile. The same is true for the reverse rotation. This slightly affected the reversibility and I further noticed that the best-returned droplets are found not exactly after the same number of turns but sometimes an extra 30-60 degree turn was required.

Discussion

The Second Law of Thermodynamics is seemingly violated in this experiment: in the 3rd subfigure (top right) in Fig. 16 and in the middle figure in Fig 17, the coherence of the ink molecules is lost. Still, it can be brought back to coherence, i.e. that the droplets are nicely visible again after the reversed rotation. Such a process contradicts of our natural sense of time: once coherence is spontaneously lost, usually it never recovers again. The key to understand the observed phenomenon is that the decoherence of the ink droplets was forced by external action and that it did not happen spontaneously. Formulated differently, no memory loss of the ink droplets' position happened. Every little layer in the Taylor-Couette flow has a "memory" of its angular speed with respect to the other layers. Therefore, when rotated in the reverse direction, each layer will recover its position with respect to the other layers, thus restoring the coherence of the droplets. Certainly, there are natural decoherence processes, such as diffusion, which results in a more smeared droplet than initially. This means that the recovery of coherence does not violate the Second Law of Thermodynamics and that it represents a realization of the Loschmidt echo.

5. Summary and conclusions

During my study, I attempted to demonstrate the so-called Loschmidt echo using laminar flow in high viscosity fluids: This is a known demonstration and my task was to identify the difficulties and pitfalls in this experiment.

I experimented with three different fluids, which yielded different results. Honey and glucose syrup were not ideal because their nonoptimal viscosity. It was also hard to manipulate these fluids because of their stickiness. The best result was achieved using cooled glycerol and with two rotations. Instances with more than two rotations did not reverse back to the original state as well as two or one rotations.

In conclusion, the emerging phenomena was due to the fact that the mixing of the droplets did not occur naturally (in a spontaneous process), but rather it was a result of an external force (rotation). In reality, there was no information loss because every layer in the laminar flow knew exactly what its velocity was. Hence, the reversing of the layers was possible. However, diffusion exist even in the most viscous fluid which is the reason for the slow spreading of the droplets. This example is what clearly demonstrates the Second Law of Thermodynamics.

Further, the realization of the Loschmidt-echo provides an example for the fact that there exist systems which seemingly contradicts with the Second Law of Thermodynamics. Indeed, the hereby examined system only reinforced the validity and the effects of the law itself.

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