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École normale supérieure

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Fights Bohr-dom

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Édito N_{14}: la NPR à l'image de la physique, curieuse et saugrenue !

Oyé oyé physiciens, physiciennes, la Normale Physics Review est là pour égayer votre journée ! Le rythme de l'année commence à s'installer, le mauvais temps pointe le bout de son nez, et les φ21 vont affronter leurs premiers partiels. Pourtant la physique reste au rendez-vous pour vous émerveiller encore et toujours. Si cette discipline nous permet d'apporter des réponses à tant de phénomènes, elle n'en reste pas moins mystérieuse et insolite : je vous renvoie notamment à la section « Photo mystère » de notre journal, pour y découvrir d'étranges phénomènes. Nous remercions d'ailleurs tous nos lecteurs pour leur curiosité et leur soutien. En tant que nouvelle recrue, j'encourage tout étudiant intéressé à nous rejoindre dans cette belle aventure physicienne ! C'est une merveilleuse opportunité que de découvrir la physique autrement et de rencontrer d'autre passionnés.

Au programme de ce numéro : beaucoup de goûters (on en viendrait presque à se demander si les physiciens travaillent parfois…), un éloge de Git et de la mécanique quantique : nanofluidique et effet Hall ! ***O. Devigne***

[Class' life]

Party of Master ICFP, 7th of October

On Thursday 7th, a party was organized to celebrate the beginning of the year and get a time for students to meet us in a friendly atmosphere. All the students from M1 and M2 ICFP were invited and could enjoy the nice ambiance made of music, snacks, quiches and beers (Figure 2). We can't mention the beers without presenting the home made beer cooling method, consisting of cooling the drinks with liquid nitrogen (Figure 1)

This can't take place without the investment of the head of the master, the master representatives and everyone who gave a little help during the event. Thank you !

Pancake party of L3, 7th of October

One week later, on Thursday 14th, another party took place (The Physics department is definitely the one where we have the most fun) ! This time some students from L3 organized a pancake party for the class, their teachers and their TD-supervisors. The goal was to get to know one another better and of course to eat some of the tasty pancakes that were being prepared by a bunch of students. Of course some cidre (*doux* and *brut*) was being served at the same time ! It was also an opportunity to meet students from other departements as students from the DMA and Philosophy came to eat some of our delicious pancakes. Thanks to the big boss Adel Bilal and Medina Mahrez for their support during the organisation of this party !

Figure 1 – *Physicists cooling beers*

[Physicists' life]

Des phénomènes quantiques à l'interface d'un fluide à l'échelle nanoscopique

Dans l'équipe Micromégas, dirigée par Lydéric Bocquet, on étudie les fluides à l'échelle nanoscopique. Depuis qu'André Geim a découvert comment synthétiser du graphène, un ma-

Figure 2 – *The party in Jardin Lhomond*

Figure 3 – *Partying around pancakes*

Figure 4 – *Behind the scenes*

tériau bi-dimensionel, en 2004, ce qui lui valu le prix Nobel 2010, les expérimentateurs sont capables de créer des nanotubes, nanochannels, ... Ainsi, on découvre de plus en plus qu'à ces échelles-là, des phénomènes étranges apparaissent. Ainsi, l'agitation thermique nécessite de prendre en compte la physique statistique ce qui modifie l'hydrodynamique classique. Aux parois, le fluide glisse, contrairement à ce que décrit les équations de Navier-Stokes. Ou encore, un flot le long d'une parois génère un courant électrique dans cette dernière.

Parmi ces résultats surprenants, Eleonora Secchi, avec l'équipe Micromégas, a découvert en 2016 que la longueur de glissement (et donc le frottement) dans un nanotube de carbone dépendait du rayon du tube. Cette découverte, publiée dans *Nature*, défie la physique classique : à ces échelles, le frottement ne dépend plus de la rugosité de la surface mais de la structure même de la paroi. C'est un changement de paradigme !

Pour expliquer ce phénomène, Nikita Kavokine, doctorant à Micromégas, a développé un nouveau formalisme théorique. Son modèle considère les interactions électriques entre les charges partielles de l'eau, agitées par l'énergie thermique, et les électrons du solide, dont les modes collectifs sont décrits par la théorie de la matière condensée et sont donc intrinsèquement quantiques. Avec cette nouvelle théorie, le frottement dépend de la résonance entre l'agitation thermique de l'eau et les modes électroniques du solide, qui dépendent de la structure interne du solide. Par exemple, celle du graphite, qui est une succession de couches de graphène, dispose d'un mode vertical qui interagit beaucoup avec l'eau. Conséquence : l'eau frotte beaucoup plus sur du graphite que sur du graphène, alors même qu'ils ont la même surface. Ainsi, son modèle permet d'expliquer les résultats de 2016, ce qui lui a valu d'être publié cette année dans *Nature*. Mais conceptuellement, ce résultat est plus profond, il démontre que l'on a atteint la limite quantique de la nanofluidique : il faut prendre en compte la structure interne des parois pour comprendre les données expérimentales.

Ma thèse, qui débute cette année sous la direction de Lydéric Bocquet, a pour objectif de continuer le travail théorique débuté par Nikita Kavokine, maintenant en post-doc à New York. En particulier, je m'intéresse à deux projets. Le premier est d'étudier le frottement dans un contexte confiné. Les expérimentateurs sont aujourd'hui capables de créer des nanochannels de moins de 7 Ångström, où seule une couche d'eau peut circuler. On arrive donc à la fois à une limite où la dynamique de l'eau va changer, et où les deux parois peuvent échanger par interaction électrique. Pour décrire un cas aussi extrême, il convient de redéfinir la notion même d'interface, et d'étudier plus précisément le recouvrement des densités électroniques de l'eau et des parois. Le second projet est d'étudier la génération de courant électrique dans les parois via des interactions quantiques. Les charges de l'eau transmettent du moment aux électrons de façon asymétrique si l'eau est en mouvement, de cela peut résulter, à partir du second ordre, la génération d'un courant.

D'un point de vue outils, les formalismes que j'utilise sont de la théorie de la matière condensée hors équilibre et de la théorie quantique des perturbations, que l'on peut notamment écrire avec des diagrammes de Feynman. À cela s'ajoute des collaborations avec des numériciens à Berlin qui nous fournissent des données de simulation, et avec des expérimentateurs, en particulier Alice Marcotte qui finit actuellement sa thèse à Micromégas, qui ont des données expérimentales à comprendre. C'est notamment l'une des forces de l'équipe Micromégas d'allier à la fois des théoriciens et des expérimentateurs pour avoir un échange fructueux et ainsi faire avancer la recherche dans le domaine de la nanofluidique ! (**Baptiste Coquinot**)

GIT FOR PHYSICS STUDENTS : WHY AND HOW

As physics students we are expected to work, one day, on big coding projects. At least for the exam of some lectures or our incoming internships. Add now a tricky constrain to this projects : you want to work collaboratively on it ! Then, how do share efficiently the files ? How to monitor the files evolution, rectify (and identify) mistakes made, propose changes without erase the code of your collaborators and so on ? There is fancy tools to do this : the software *Git* and the remote hosting services such as *GitHub* or *GitLab*. I propose you to present briefly *Git* , its features and the hosting services.[1]

What is Git ?

Git is a version control system, namely a software for tracking change in files, usually text files as coding scripts, LaTeX files. It was created for the development of *Linux* (a long time ago... in 2005 !) to allow many developers to contribute to the development of the kernel. Before going further into its characteristic, let's precise that *Git* is a a free and open-source software available on every operating system.

The idea is to monitor the evolution of a set of files - **a repository**- (roughly files packed into a folder) in a structured way. In order for example to track local changes in a script or edit several versions of it, without creating a new file each time. Usually, what you may do is to save your files after modify them, go to sleep and start again tomorrow. Well, with *Git* you do exactly the same. You only just in addition update the **repository** to tell it the changes you made - that's **a commit**. What's nice is that you can only choose to commit a few files, not all the files of the folder. Then if you have for example two python scripts, in one you manage to code a new function and in the other you missed time to finish writing it, you can choose to commit only the first one. In the **repository**, only the changes made on the first will be finally recorded. This are the main things one need to know before using git. There is more powerful features : on big projects, you can want to work on new feature, for example implementing a new analysis method. And you need to keep your original project (which work pretty well !) clean. A basic way to do it is to duplicate the folder and work on the copy. A cleaver way is using *Git* and the **branches** feature. What you can do is to fork the project into two branches (or more), keep the clean one - the **main**- and start to work on the development branches. At the end, you just have to **merge** the branches.

Here it is for the main features of *Git*. Note that all that were exposed above take place in our local machine- we don't share files or store them on a remote cloud. And that is precisely the point I would like to discuss now : how to work collaboratively with *Git* ? This is were hosting services come in. This platforms act as a cloud on Internet, but developed to be used with *Git*. Now, you continue to manage your project as discussed before, but with periodically **push** the changes on the remote server to update the remote repository. And invite collaborators to also push their commits on the repository ! You will be after able to get it on your local machine and update your local repository. And so on...

I want to use *Git*, how get started ?

The first things to do is to install the software *Git* on your computer and choose a hosting service. Then, I advise you to follow the guidelines you can find on the hosting service website, or follow documentation of the official git website : `https://git-scm.com/`.

The first steps with this can be really painful (at least as much as when you start walking) but it is possible to master a large panel of really useful features in a very short time. And then being comfortable with using daily *Git* and collaborate on projects, or documents writing. If you need to go further in development, there is a time a will converge to *Git*, for example to use some python open-sources packages published on the hosting services. (**L.Brivady**)

RECOMMANDATION POUR LA PHYSIQUE DES SOLIDES

Qu'il est parfois dur de vouloir approfondir un cours de physique sans avoir les références nécessaires. Je vous propose dans l'article qui suit de vous présenter un livre qui m'a été bien utile en L3 : *Physique des Solides* de Niel W. Ashcroft et N. David Mermin. Avant de commencer, il faut bien noter que je ne dis pas que les autres livres traitant de physique du solide ne sont pas bons ! Au contraire, ils le sont mais celui qui m'a été le plus utile est celui-ci.

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[1] I would like to emphasise that this won't be a tutorial on *Git*, only a short introduction and guidelines on where find relevant information.

Il faut tout de même faire attention à quelque chose : c'est un ouvrage de référence pour beaucoup de chercheurs et beaucoup de professeurs. Il est donc adressé à un public averti. En effet, il peut être très compliqué à comprendre en première lecture mais en passant un peu de temps sur certains passages, tout se passe bien au final !

Le cours de physique du solide qui m'a été dispensé l'année dernière était inspiré de ce livre. C'est donc en partie pour ça que je l'ai choisi. En plus de sa clarté, le livre est très bien structuré ce qui nous permet de bien le comprendre et de retrouver les notions dont on a besoin rapidement.

Un large spectre de sujets en lien avec la "*physol*" est proposé et il est agréable de simplement parcourir le livre pour découvrir de manière succincte toutes ces notions. Ce qui est aussi intéressant c'est qu'il propose, avant de complètement entrer dans le sujet, des rappels de mécanique quantique et de physique statistique qui sont deux disciplines au cœur de ce domaine.

Un point non négligeable est que ce livre passe un certain temps à exposer les théories historiques de la physique du solide (je pense notamment au modèle de Drüde) qui étaient les premières théories utilisées pour étudier le déplacement des électrons, par exemple. Il prend donc un aspect historique mais aussi moderne avec la physique quantique et statistique. Nos nouvelles théories sont plus fines qu'à l'époque ce qui nous permet donc de faire plus de prédictions et d'être plus précis.

Un des autres avantages de ce livre est le nombre de schémas qu'il contient. Il est toujours bien de comprendre les développements calculatoires mais il est aussi primordial d'avoir une représentation des concepts physiques mis en jeu. Prenons pour exemple le cours sur les liaisons fortes : en cours, je n'avais pas correctement compris les parties calculatoires et surtout le but de ce chapitre. Grâce à ce livre, nous pouvons comprendre plus facilement son intérêt et ses applications. Grâce à certains schémas (très bien faits et très bien détaillés), ce chapitre devient d'un coup plus physique qu'avec simplement des équations.

Vous pourrez le trouver (bien entendu en quantité limitée) dans la Bibliothèque des Sciences expérimentales de l'ENS (au 29, rue d'Ulm). Mon avis ne conviendra pas nécessairement à tout le monde mais c'est un début pour approfondir ses cours ! (**Rodrigue Orageux**)

L3 internship : Quantum Hall effect

This title may ring a bell for some of you as it is the topic of the first physics seminar made by Gwendal Fève, my internship supervisor.

I found my L3 internship thanks to Jean-Marc Berroir's course on quantum mechanics. While talking about the statitics of Bosons and Fermions, he said that we could create particles with statistics between the ones of Fermions and Bosons, those particles are called Anyons. It appears that Anyons can be observed in a quantum Hall regime and that Jean-Marc Berroir and his team were working on it at the LPENS. I simply sent a mail saying that I wanted to visit the laboratory and, impressed by the physics they were doing, I ended up doing my internship here. We have the chance to follow courses made by researchers and sometimes those courses can provide you a good internship subject, even in L3.

The classical Hall effect is really useful in daily life and not that much complicated to understand : Take a plan conductor. Put a magnetic field perpendicular to the conductor. If a current goes through the conductor, a perpendicular tension will appear due to the deviation of electrons by the Lorentz force.
The quantum Hall Effect is a good example of the relation :

$$\hbar(\text{simple Classical effect}) = (\text{complicated Quantum effect})$$

Indeed, when you are working with quantum Hall conductors, what you observe strongly depends on the strength of the magnetic field that you use and on the shape of your conductor. Here is some interesting observations that we made during my internship :
- In the quantum Hall regime, the current only propagates at the edge of the conductor.
- Even if your conductor is made of electrons, when you will want to measure the charge of the current carrier (through shot-noise for instance) , this charge will not be $-e$. This charge will actually depends on the strength of your magnetic field.
-Those current carriers are not Bosons nor Fermions, they are Anyons. We also say that they are quasi-particles.
-You observe a quantification of the Hall-resistance. (see figure 1)
If you are puzzled by those notions of quasi-particle, current which only propagate through the edge, it is normal ! Some aspects of the quantum Hall effect are still not theoretically perfectly understood.

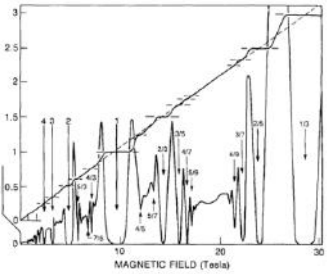


Figure 5 – *Quantification of the Hall Resistance*

Aside of understanding and measuring those effects, experimenters also work in order to repair/survey/improve their experimental set-up. As for my self the major piece of the set-up was a huge fridge which could cool down to 10 mK.

Figure 6 – *the Fridge*

Even if you are more into theory, an experimental internship is a really great experience for various reasons :
- as you work with physicists there is 99.9 % chance that they are cool.
- you can understand how theory is strongly linked with experiments.
- experiments allow you to understand some effects wich are theoretically hardcore to describe.

(**Simon Douaud**)

L3 Internship : Energy spectra of a turbulent flow

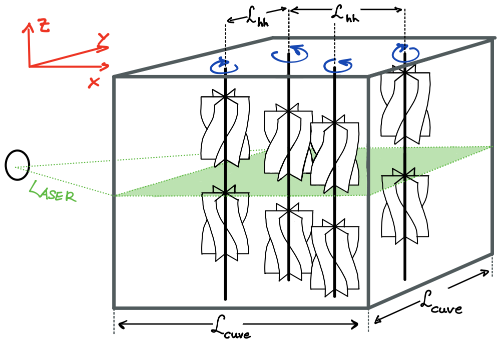
I did my L3 experimental internship in the fluid dynamics team here at ENS, under the supervision of Stéphane Perrard, who you may have seen in experimental lab projects (TPs) or in hydrodynamics tutorials. The goal was to tackle the experimental challenge of measuring tridimensional correlation functions and energy spectra in a turbulent flow.

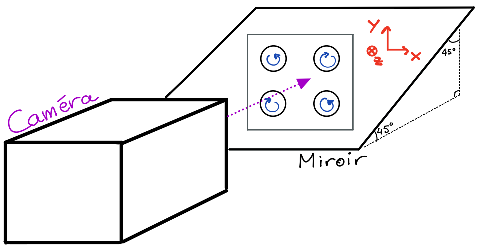
Turbulence : what is it, and why should we care ?

Turbulence is a phenomenon which is actually rather hard to define exactly. It refers to a quality of certain fluid flows, which display very complex spatial and temporal organizations involving many different time- and length-scales, as well as velocity fluctuations in time and space which we can't fully predict and see as random events. They are omnipresent around us, be it the swirls of water in a torrent, the mixing of coffee and milk, the motion of clouds in the sky, and many, many more examples.

What my internship was about

In the first half of the last century, Kolmogorov (1941) and others managed to theocratically describe the transfers of energy between the different length scales of a turbulent flow, under some hypotheses. What they found was that the energy was injected at some length scale $\mathcal{L}$ and *cascaded down* at a constant rate from there to the smallest scales, where viscosity would dissipate it. The quantity they computed was the *energy spectrum* $E(k)$ (which roughly describes the amount of turbulent kinetic energy carried by structures of size $\sim 1/k$ in the flow), for which they found a power law $E(k) \propto k^{-5/3}$ for scales smaller than the injection scales but larger than the dissipative scale η (i.e. for $\mathcal{L}^{-1} \ll k \ll \eta^{-1}$). This law has been experimentally verified numerous times now, for many types of turbulent flows. One thing that is, on the contrary, inexistant in the literature is the study of the energy spectrum at scales larger than the injection scale $\mathcal{L}$ (equivalently, for $k < \mathcal{L}^{-1}$). As it turns out, it's much harder to study the small-k spectrum because it's computation depends critically on the tridimensionality of the measured velocity fields (which turns out not to be the case for the large-k spectrum, which can be computed from even 1-dimensional velocity measurements).





The goal of my internship was thus to find and implement an optical method based on Particle Image Velocimetry (PIV) to measure velocity fields in a volume of fluid, using the equipment which was already available in the lab (which was very good, but not suited for naive methods such as filming with two cameras in a volume illuminated by a wide laser beam). The actual experimental setup was made up of a cubic tank with four motors piloting each a pair of chiral helices. The chirality of the helices and the fact that each motor is controlled individually means that many different flow geometries are available to us in this one setup.
The solution we came up with during my internship was to measure the velocities in only two planes separated by a known distance Δz, using standard 2-d PIV techniques. We would then change Δz over time to get measurements inside a full volume of fluid. This approach is valid as long as the time it takes us to sweep out the volume in this way is considerably smaller than the timescale at which the mean flow changes, which was not a problem at all. Doing this, we manage to measure the energy spectrum of the flow, and find something which is both consistent with the $k^{-5/3}$ spectrum at large k, and which is compatible with a k^2 spectrum at large scale. This is a very exciting result, both because it is consistent with theoretical predictions (e.g. Batchelor *et al.* 1956) and because it hints at a possible energy equipartition between the large-scale Fourier modes (recall from your statistical physics courses that indeed, $E(k) \propto 4\pi k^2$ is the spectrum of a 3-dimensional system in which the energy is equally distributed between the Fourier modes).

The internship overall was very interesting and very rewarding ! I spent a large part of my time coding the Matlab scripts we used to analyse the experimental data (series of $\sim$ 60000 2-d velocity fields per 2-minute experiment !), and most of the remaining making actual experimental measurements. These were both exciting and nerve-racking because the setup is pretty complicated and uses a powerful laser, which has to be handled carefully. The team was very excited when we managed to compute the spectrum, because this was a very anticipated result that they've been waiting for for about a couple years. Obviously I was also ecstatic, so much so that I decided to keep working on this project during this first semester as a supervised experimental research project ! What we want to explore now is the robustness of this result to changes in our control parameters (e.g. the geometry and the velocity of the helices forcing the flow).
(**Thibault Raymond**)

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Sir I have a question

Vous aimez vous casser la tête sur des questions existentielles ou simplement réfléchir à de petits problèmes à la volée : cette rubrique est faite pour vous !
Voici une sélection de 10 questions qui pourraient vous inspirer...

I : The strength felt by a magnetic momentum in a magnetic field is $\overrightarrow{grad}(\vec{m}.\vec{B})$. How would you compute the magnetic momentum $\vec{m}$ of a cylindrical permanent magnet of volume V and of magnetic permeability μ_r ?

II : What's the lowest frequency ever reached by a laser system ? Why is it difficult to have Doppler cooling of molecules ?

III : How long would it take to dissolve a spherical soap of radius R within a water jet of radius $R_w > R$ with a uniform volumic flow $\vec{J}$?

IV : Gas storing companies dig cavities in geological saline layers (like *Storengy* in France). The process is to send a flow of water with a flow Q to dissolve the salts. The experience shows that the higher the flow is, the more spherical the cavity gets (otherwise, one gets a cylindrical cavity). Can you explain this result ?

V : Estimate the energetic efficiency of muscular contraction

VI : Take a network of N neurons, each neuron make K connections and connection strengh is J. How should evolve the connection strengh with the size of the network to keep the dynamic unchanged ?

VII : Consider a biotope and rank the animal species by decreasing population. How the size of the population species are distributed regarding their ranking ?

VIII : Why is the metropolitan sometimes so noisy ?

IX : Does heavy water taste the same as normal water ?

X : Could we define a frame of the Universe ?

ABOUT THE PREVIOUS QUESTIONS...

I. QUESTION IV OF N_{13}

The *Tour de France* is known to be one of the most demanding cycling race. During 3 weeks, cyclists ride daily between 4 and 5 hours in a stage in average, might face awful weather or climb exhausting ascents. And fast (the last edition average speed was 41 km/h, for 3410 km). To be competitive, cyclists must be as fit as possible and reduce their fat mass lower than 10% of their weight (in contrast, for a sedentary man the proportion is 20%). So they can lose weight without endanger their health. Indeed, one can see that cyclists surprisingly don't lose so much weight during the *Tour de France*, around ±1 kg. Then one can wonder how much calories they should eat daily.

First, let's estimate the basal metabolism of a human. In previous notes, we assume that our energetic consumption at rest is the same of a lamp, around 100 W. This gives a daily energetic consumption of 2000 kcal. Not so far of nutritional recommendations which are 2500 kcal every day for a man. The difference could be simply explained by the fact that we don't take into account any supplementary activity in our estimation, whereas the recommendations are supposed to be an average estimation over all the population.

Then, what is the consumption of a cyclist during a stage ? Assume first that the yield of muscular contraction is about 25% (see Questions section) and that the average power delivered by a rider in a stage is 300 W. We get for a 5 hours stage an energetic cost of 6 kWh, namely 5100 kcal. Finally, we assess that the daily energetic cost for a rider is about 7100 kcal. This result is in the range of the expectations of nutritionists taking care of the riders [1]

Just for fun : a pizza is about 1000 kcal [2], the energetic supply of such athletes would then represent around 7 pizzas per day ! (**L.Brivady**)

References

[1] *Le Point* article
[2] USDA website

MYSTERY PHOTO

The mystery photo of our current edition is shown on Figure 7. Could you guess what is it ? We warmly thanks Simon Tragust for his picture !

Figure 7

[ACKNOWLEDGEMENTS]

We thank our contributors for their fantastic articles and questions. We also thank everyone who send us their feedback and encouragements. And thank you dear reader !

We need you !

If you would like to contribute or support us, don't hesitate to contact us :

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