GENERAL NOTE

Design and Superconducting Levitation

Julien Bobroff, François Azambourg, Clémentine Chambon and Veronica Rodriguez

ABSTRACT

When specific metals are cooled to a very low temperature (typically colder than about -200°C), they become superconductive and can make magnets levitate. This paper reports on a collaboration between physicists and designers to exploit this quantum levitation. The main goal of this collaboration was to create artistic displays, experiments and videos to engage a large public with fundamental physics. Beyond its public success, this "SupraDesign" project enabled an encounter between two communities: researchers in physics and designers. The collaboration revealed unexpected similarities in working methods, such as testing through experimentation, engaging in teamwork and making use of creativity in a constraining environment.

Levitation—whether it originates from a magnetic, electric or mechanical source—has always been a great source of fascination. However, its very unstable nature has made it difficult to use in everyday chores or even in works of art. In 1986, two physicists made a discovery that changed everything: They demonstrated that certain types of ceramics become superconductive at -200˚C (about -300˚F) [1,2] and in such a supercooled state can make magnets levitate with remarkable stability. It is even possible to move the ceramic or turn it upside down—the magnet seems to stay "hooked" however the ceramic is turned [3]. However, the need for liquid nitrogen to cool the ceramic has to this day limited the technological and artistic applications of this phenomenon.

In 2011, on the occasion of the centennial of the discovery of superconductivity, scientists specializing in superconductivity offered to work hand in hand with students from an industrial design school, the École Nationale Supérieure de Création Industrielle (ENSCI), in order to revisit this type of levitation and its applications [4]. Professional designers and scientists supervised 13 students who spent one semester working on 10 projects related to superconductivity: demonstrations, works of art, games, futuristic videos, etc. All these projects were then used in exhibitions, conferences, scientific fairs or in the media, as gateways to quantum physics.

This teamwork between physicists and designers in an educational context opened new fields for popular science. Indeed, as shown here, the designers were able to propose a more attractive and imaginative way to display fundamental phenomena than the usual pedagogical approaches. Unexpected similarities in working methods between scientists and designers were also discovered.

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Article Frontispiece. Alexandre Echasseriau, one of the levitating animals in *SupraCircus.* (Photo: Veronique Huygue. © SupraDesign ENSCI & Université Paris Sud.)

Superconductivity and Levitation

Discovered in 1911, superconductivity is a phenomenon that appears in many metals at a very low temperature. When a metal becomes superconductive, it starts conducting currents perfectly, without any electric resistance or becoming heated. Moreover, if a magnet is brought close to a superconductor, the latter generates electric currents that repel the magnet and cause it to levitate (Fig. 1a). In certain types of superconductors called "type II superconductors," the situation is more complex: Instead of the magnetic field being completely repelled, a compromise situation is created, in which the magnetic field penetrates the superconductive material along tiny tubes called "vortices." These vortices tend to pin themselves on certain points of the material. The magnet still levitates but is now hooked to the ceramic material by these magnetic tubes, which work like tiny invisible anchors. If the magnet is pulled away, the superconductor stays magnetically hooked and becomes suspended—as shown in Fig. 1b. In 1986 the discovery of new types of ceramics that could become superconductive at a much higher temperature (as high as about -120˚C or -184˚F) opened new fields of research which are very active today. However, the origin of superconductivity in these ceramics still remains one of the greatest scientific mysteries [5].

Besides the need of liquid nitrogen to cool the superconductor, levitation and its applications depend on two factors: elevation (height of the levitation) and the anchoring or pinning force [2]. The levitation height is proportional to the power of the magnet. With the most powerful magnets (such as alloys of neodymium, iron and boron), the elevation can reach a few cm (or an inch) at best. For higher levitation, one would need powerful electromagnets, an impractical situation. The pinning force holding the magnet above the superconductor depends on both the levitation height and the quality of the superconducting ceramic. This force can support weights of several kilograms for elevations of about 1 cm (0.4 in). A magnet can hence levitate above a superconductor at an elevation of about 1 cm and bear the weight of several kilograms. All the projects described herein, whether real or imaginary, had to proceed within these constraints.

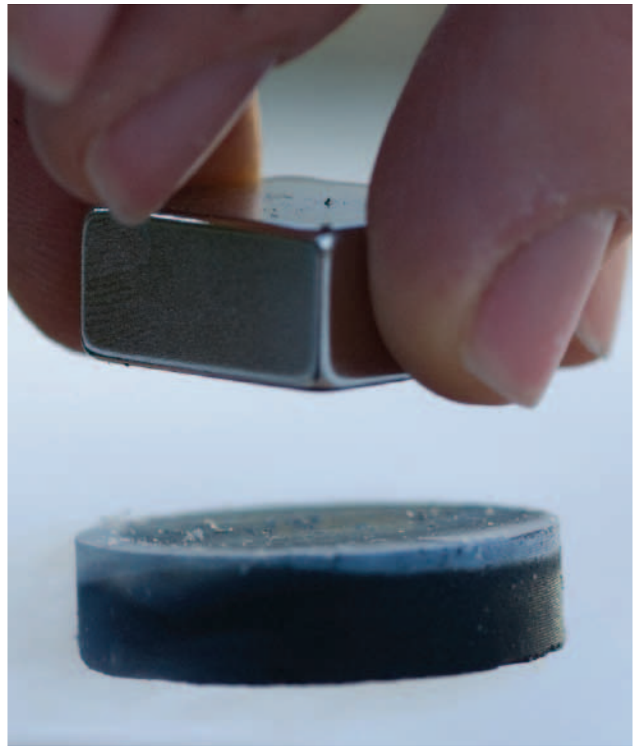

Fig. 1. (a) Levitation. A magnet (the metal cube) levitates when placed above a superconducting disc (the black puck) cooled at -196°C (-320°F). (b) Suspension. If the magnet is lifted, the disc remains magnetically "hooked" to the magnet and the gap between the magnet and the superconducting disc does not change. When the magnet is raised, the disc levitates. (Photos: Jeffrey Quilliam and Julien Bobroff. © SupraDesign ENSCI & Université Paris Sud.)

The SupraDesign Project

In 2011, to celebrate the centennial of the discovery of superconductivity, the Centre National de Recherche Scientifique (CNRS) organized a variety of events all over France for the public: exhibitions, animations, science fairs, meetings, films and websites [1]. The scientists conducted different experiments featuring levitation involving a train, a Möbius strip, a hula hoop, an Eiffel Tower and even a "hoverboard" (the levitating skateboard in *Back to the Future*) that users could ride to levitate above a magnetic rail [6]. Beyond these experiments, the general aim of the events was to explore new kinds of outreach in collaboration with science educators in science museums, artists, graphic designers and designers. This is how the SupraDesign project was born—through physicists and designers working together to meet the need for physics to be expressed in concrete ways that captivate the public at large. The goal was simple: to use the tools of the designer to show superconductive levitation and to imagine what it could be used for in the future.

SupraDesign was developed in Paris at ENSCI-Les Ateliers, a design school that uses educational methods based on practical projects. ENSCI offers a multidisciplinary training course that is both theoretical and practical. The students come from diverse backgrounds. Among the 13 students involved in the SupraDesign project were a former bronze craftsman, a former management accountant and students from Israel, Canada and Italy. The school is open 24 hours a day, and the students are all mixed together, regardless of their experience, rather than grouped according to their years of study. Each student decides on his/her own course and projects; the full course lasts from 3–5 years. The projects are supervised by professional designers and

Fig. 2. Charly Zehnlé, luminous sculpture hanging in the air. (Photo: Julien Bobroff. © SupraDesign ENSCI & Université Paris Sud.)

funded by outside partners. The SupraDesign project was carried out by a working group called "Formes et Matières" ("Shapes and Materials"). The guiding principles of this working group, run by François Azambourg and Clémentine Chambon, are based in pragmatism: The students try to answer a precise question through experimentation. This system teaches future designers to try out different ways to build an object and to test the materials through direct manipulation in order to understand their characteristics. As far as the SupraDesign project was concerned, the students were given a very simple starting point: superconducting levitation. First, they did a few experiments to understand the phenomenon. Workshops, guided tours of physics labs and seminars on the subject of superconductivity acquainted them with this type of levitation and helped them understand the physics involved. Once familiar with the subject, they were free to experiment. They proposed projects in several domains: security, hygiene, games, food, household use, sound, art, sport, beauty and even puppet animation. This project was able to explore a wide variety of subjects, thanks to the help of the teachers—designers who made sure that every student explored a different path.

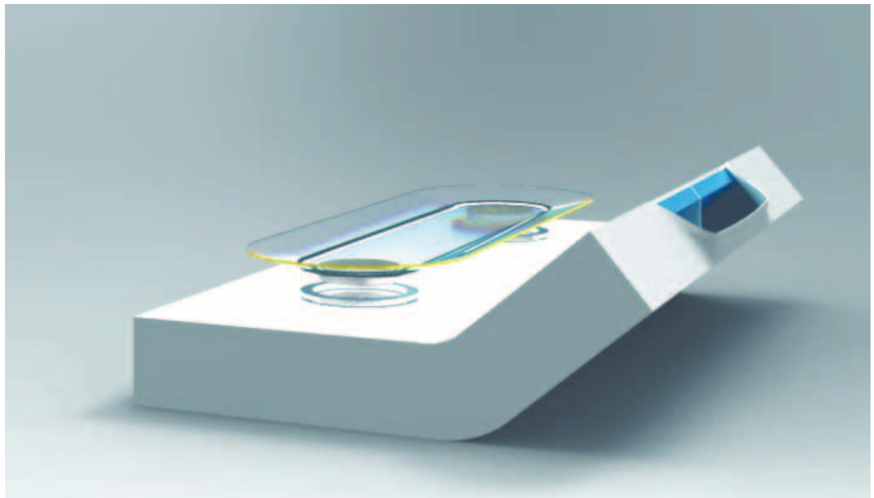

Fig. 3. Piotr Widelka, superconducting loudspeakers that make the levitating platform dance and emit sound. (Photo: Piotr Widelka. © SupraDesign ENSCI & Université Paris Sud.)

Fig. 4. Alexandre Echasseriau, performance of the superconducting circus *SupraCircus*. (Photo: Julien Bobroff. © SupraDesign ENSCI & Université Paris Sud.)

Projects Rooted in Reality

Some of the students decided to choose practical projects displaying levitation in artistic devices, games or experiments. The artistic project *Quand la nuit tombe, les lumières tournent* (*When the night falls, the lights turn*) created by Charly Zehnlé consists of a luminous sculpture (Fig. 2). Drifting under a superconducting structure and held by invisible superconducting vortices, this sculpture spins in the air with no bonds, absolutely free. Little LED lights turn and shake while nitrogen smoke floats down from the superconducting structure above. This sculpture was displayed for the public in a dark room with electronic music, conveying an enchanting atmosphere.

Piotr Widelka invented a dancing superconductor: a magnetic platform levitating above coils wound around superconductors (Fig. 3). When the coils are plugged into a portable audio player, they make the platform vibrate by induction. The vibration depends on the frequency and the amplitude of the music, so the platform appears to be "dancing" to the rhythm of the music. Furthermore, the vibration of the platform transmits the sound of the music, as does the membrane of a loudspeaker, but in levitation. This object, both entertaining and technical, was used in a public demonstration on superconductivity at the Cité des Sciences et de l'Industrie science museum in Paris. In a similarly amusing yet technical vein, Abdel Malek Boumellil created *Supra Station*, a maze in which a magnet is controlled from a distance by a superconducting handle. The player uses the handle to move the magnet from a distance and make it find its way out of the maze. This interactive game is perfect for children, who can experiment with the physical forces at play in levitation.

In science fairs, superconductivity is usually illustrated with simple levitation experiments (as in Fig. 1) or with superconducting trains in levitation on magnetic railways. Alexandre Echasseriau offered a new route to public demonstrations with *SupraCircus* (Fig. 4). Inspired by sculptor Alexander Calder, *SupraCircus* features small fluffy (fake) birds in a wooden circus set. The circus emerges from a suitcase with multiple compartments. The showman becomes orator, experimenter and puppeteer at the same time. In front of the audience, he handles his tiny birds and tells stories full of jokes, stunts and, of course, physics.

During the performance, a pink bird dances the cancan in levitation (Article Frontispiece and Color Plate C). A little hairy devil rides magnetic ramps. A penguin rides a levitating Ferris wheel. A tiny

Fig. 5. Delphine Mériaux, levitating superconducting jewels. (Photo: Delphine Mériaux. © SupraDesign ENSCI & Université Paris Sud.)

Fig. 6. Marion Gros, superconducting socks levitating above magnetic soles. (Photo: Marion Gros. © SupraDesign ENSCI & Université Paris Sud.)

white bird is shot from a cannon powered by liquid nitrogen. Each act is accompanied by an explanation of the science behind it. The first time it was tested in front of an audience, the circus aroused both laughter and curiosity, while enabling the audience to overcome their reticence towards fundamental physics.

Samuel Bernier and Udi Rimon created a video showing a superconducting breakfast, inspired by the cooking machines of Rube Goldberg. In this video, superconductivity is used to make kitchen objects levitate: food in the fridge, cutlery, the egg in its eggcup, the orange about to be squeezed. This experiment explores the connection between fundamental phenomena such as superconductivity and our daily habits.

Projects in Design-Fiction

Although many experiments are conducted in laboratories all around the world, scientists are still unable to predict whether superconductivity will one day be possible at room temperature, without cooling. However, some of the students decided to accept this possibility in order to invent new applications. Since verifying their hypotheses through testing and experimentation was a mandatory part of the project, they were asked to conduct actual experiments with liquid nitrogen to prove that their ideas were feasible in terms of distances, forces and materials. After that, they were free to pretend that the nitrogen was not needed and to imagine and present their applications.

Delphine Mériaux displayed an assortment of magnetic jewels that levitate on the body after some invisible superconducting cream is applied on the skin. There is no need to clip on a necklace and no friction, only the essence of the jewels with the body for support (Fig. 5). Another idea was to apply a magnetic cream and to use superconducting jewels that would drift freely along paths drawn on the skin.

Marion Gros created a wide variety of sports accessories using superconducting textiles: socks that levitate above soles to avoid blisters and sweat (Fig. 6), a T-shirt that makes a backpack levitate to avoid friction and knee pads that maintain the protective shell an inch away from the knee to absorb eventual impacts. In theory the textile is created thanks to a superconducting powder that is added to the cloth.

Anne-Laure Weill thought of using superconducting levitation to create new products for household use: a pan that can be held without touching it, to avoid burns (Fig. 7) and new storage facilities that can be suspended under ceilings. Elsa Tarrago and Caroline Burzynski invented UPON, a material consisting of a multitude of levitating balls and magnets separated by air. A mix of solid and gaseous states, this light granular material could be used to build new types of mattresses (Fig. 8), bumpers, or building sets for children.

What We Have Learned

The SupraDesign project led to an exhibition at the Cité des Sciences and at the Espace Pierre-Gilles de Gennes (Paris, France). There was also wide media coverage of the project on the Internet, on French national television and in the newspapers. Scientists are now using the videos created by the students who participated in SupraDesign to illustrate their own work at public conferences. Physicists show the videos at the end of their conferences to give a glimpse of what the future could be like, or at science fairs to captivate the public. Some of the objects that were created are used in scientific exhibitions in French science museums

(Cite des Sciences and Espace Pierre Gilles deGennes). A simpler version of *SupraCircus* has now been developed for wider distribution (see <www.physicscircus.com>).

In addition to being a great public success, this project proved that design can be used to imagine new applications for advanced technology and as a tool to show new aspects of modern physics and reach a broader audience. Finally, this project enabled the encounter of two communities: researchers in fundamental physics and designers. Working hand in hand has made us realize that despite the major differences between our professional worlds, we share many working methods, such as testing through experimentation, working in teams and utilizing creativity in a constraining environment. This is probably the reason why this encounter was so productive and why we have kept exchanging views ever since. There is now a new class at the ENSCI Design School on recent discoveries in physics. Likewise, a new class inspired by the educational methods of the ENSCI has been created at the Université Paris Sud to teach methods of popularization and outreach. Designers and physicists are currently collaborating on new projects on other subjects related to fundamental physics such as quantum physics [7], and we are confident that they will lead to unexpected illustrations of science through design.

The videos, pictures, drawings and sketchbooks of the SupraDesign project can be found at <www.supradesign.fr>. All the project videos and other levitation videos can be found at <www.youtube.com/vulgarisation>.

Fig. 7. Anne-Laure Weill, a pan that can be held without being touched, thanks to superconducting pinning. (Photo: Anne-Laure Weill. © SupraDesign ENSCI & Université Paris Sud.)

Fig. 8. Caroline Burzynski, a mattress built with a light superconducting granular material. (Photo: Elsa Tarrago and Caroline Burzynski. © SupraDesign ENSCI & Université Paris Sud.)

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Alexandre Echasseriau, one of the levitating animals in *SupraCircus.* (Photo: Veronique Huygue. © SupraDesign ENSCI & Université Paris Sud.) See article by Julien Bobroff et al. in this issue.