50 Years Ago

Learned behaviour is reported to be transmitted by injecting into untrained animals fractions or homogenates, containing RNA, from the cerebral hemispheres of trained rats … The transfer problem is very important for the understanding of memory and learning, and we have carried out a series of experiments with rats … Each recipient was given intraperitoneally 1 ml. of a solution containing total brain RNA extract from one donor … A general trend is revealed … which shows that injectees which received extracts of trained donors performed better than recipients of control brain extracts … Our findings do not, of course, indicate whether they concern the transfer of some specific memory mechanism or simply of a certain kind of excitatory state.
From *Nature* 14 October 1967

100 Years Ago

Meteors of the largest type exhibit a propensity to appear in the twilight of early evening. On Monday, October 1, at 6.37 p.m., a splendid object of this class presented itself, moving slowly along an extended flight in a south to north direction … descriptions have been received from places so wide apart as Weston-super-Mare, Somerset, and the extreme North of England … The Rev. J. Dunn, of Weston-super-Mare, describes the fireball as very brilliant, passing just above Capella. It was visible for five seconds; the head was some ten minutes of arc in diameter, and it threw off a short, reddish tail of sparks … Mr. T. J. Moore reports from Doncaster … that about one minute after the object had passed a very loud explosion was heard … Spectators agree as to the remarkable brilliancy of the object, and state that it aroused apprehension in cases where its nature was not understood.
From *Nature* 11 October 1917

ENGINEERING

Liquid metal pumped at a record temperature

Although liquid metals are effective fluids for heat transfer, pumping them at high temperatures is limited by their corrosiveness to solid metals. A clever pump design addresses this challenge using only ceramics. SEE ARTICLE P.199

KONSTANTINA LAMBRINOU

Every energy-conversion process produces heat as a product or by-product. Thermal energy is therefore one of the most abundant forms of energy in the industrial world. The conversion of this heat to more-useful forms of energy would dramatically improve the efficiency of many industrial processes and has been the focus of intensive research. Thermal energy is most valuable when it's transported, stored or converted at high temperatures (greater than 1,300 kelvin[1]). However, few materials can ensure reliable heat transfer at such temperatures without either melting, losing their load-bearing capacity or corroding. On page 199, Amy *et al.*[2] use a careful engineering design to bypass the inherent weaknesses of ceramic materials[3], such as brittleness, and construct an all-ceramic pump system that is capable of circulating liquid tin at temperatures of up to 1,673 K.

Liquid metals, if pumped at high temperatures, have many appealing properties[4] that could enable extremely efficient heat transfer and storage. Such properties include low viscosity above the metal's melting point and high thermal conductivity. However, the use and circulation of liquid metals at high temperatures has hitherto been limited by the inherent corrosiveness of these fluids to metallic structural materials[5]. Amy *et al.* report that their all-ceramic device can pump liquid tin for 72 hours at 1,473 K, with peak temperatures of up to 1,673 K. The successful demonstration of their proof-of-concept pump shows how clever design can lead to important technological advances.

Liquid-metal pumps need to operate in challenging conditions that involve dynamic and tensile loads, large thermal gradients and contact with a highly corrosive liquid metal. Instrumental to the performance of Amy and co-workers' pump are the ingenious design of the pump system, the correct choice of structural materials and the precise fabrication of the pump's components. The authors use a pump system that brings only ceramic materials in contact with the liquid tin to mitigate undesirable corrosion effects: they use graphite for the liquid-metal reservoir, piping, joints and seals, and a nitride-based ceramic known as Shapal Hi-M Soft as the primary pump material (Fig. 1a).

Because both graphite and Shapal can be easily shaped using machines, Amy *et al.* could precisely fabricate pump components that have a complex geometry, such as the teeth of the pump's gears. Moreover, the authors could exploit the fact that graphite expands laterally under compression to achieve dynamic sealing — a key requirement for pumping liquid metals at high temperatures, whereby the pump system guarantees fluid containment in the presence of moving parts.

Amy and co-workers' pump system also accounts for misalignments caused by thermal expansion and large thermal gradients across the system during operation. For instance, the pump's temperature is about 1,500 K, whereas the temperature of the motor driving the pump is about 300 K. The authors purposefully offset the pump and motor in the vertical direction at room temperature, so as to correct for misalignments that occur when the pump is in operation (Fig. 1b).

The authors' pump operated without mechanical failure of any of its components during testing. However, the short duration of the test (72 hours) cannot provide concrete evidence of the transferability of this technology to an industrial scale. After testing, Amy *et al.* reported appreciable wear on the gear teeth, which invites improvement in the choice of structural material and the use of elastohydrodynamic lubrication — in which the perfectly polished gear teeth are separated by a thin film of liquid metal. Additionally, the authors suggest that Shapal could be replaced by fine-grained, durable aluminium oxide to decrease abrasive wear at the points of contact between interlocking gear teeth.

Amy and co-workers indicate that the pump design allows for flexibility in the choice of structural materials to improve performance or reduce cost. For instance, graphite could be replaced by other sealing materials that have a hexagonal crystal structure, such as boron nitride. Other candidate hexagonal ceramics not suggested by the authors are the structurally layered carbides and nitrides known as the MAX phases[6]. Such ceramics can be easily shaped into components that have a

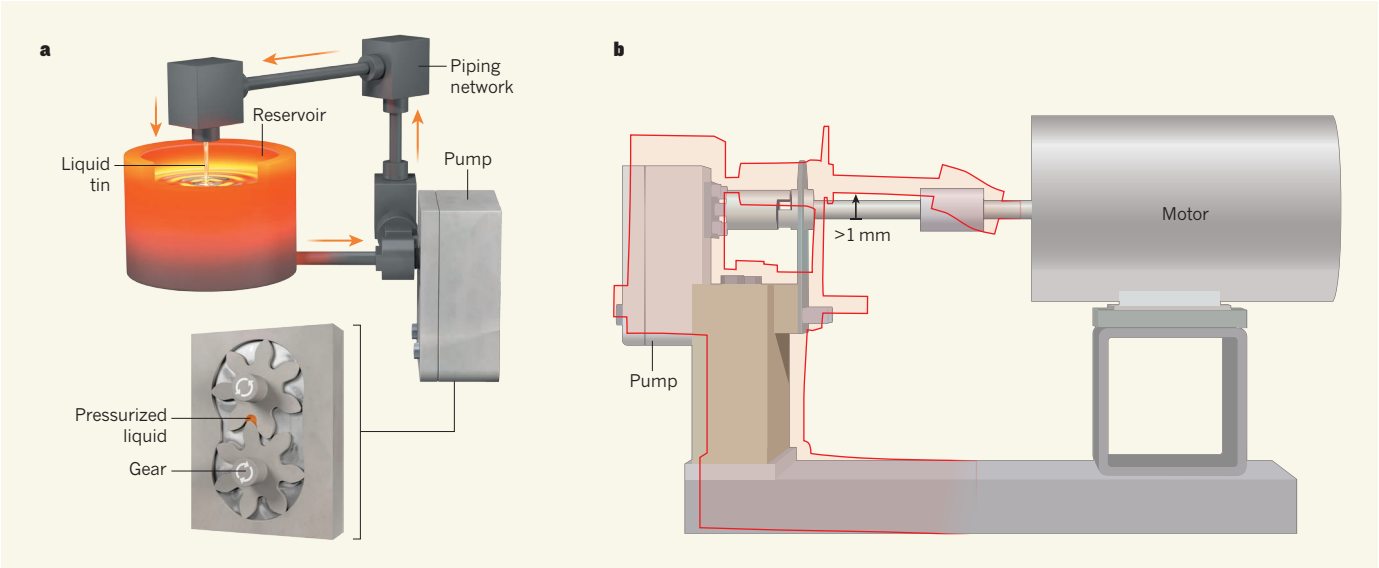

Figure 1 | Liquid tin circulated in an all-ceramic pump system. **a**, Amy *et al.*[2] report a pump system that circulates liquid metal up to a record temperature of 1,673 kelvin. The system consists of a graphite reservoir that stores liquid tin, a graphite piping network and a ceramic pump. The reservoir feeds liquid tin into the pump, where a pair of gears pressurizes the liquid, forcing it through the piping and back into the reservoir. The orange and white arrows indicate the flow of the liquid tin and the rotation of the gears, respectively. **b**, During operation, the pump, the motor driving the pump and the parts connecting the pump and motor become misaligned as a result of thermal expansion. The red regions indicate the position of the system at the operating temperature — the authors observe more than 1 millimetre of vertical displacement. Amy *et al.* purposefully misalign the pump system in the vertical direction at room temperature to account for expansion when the system is hot. (Figure adapted from ref. 2.)

complex geometry and are characterized by an exceptional compatibility (a lack of chemical reactivity) with liquid metals.

Undoubtedly, each pump system will need to be optimized with respect to both design and material choice according to the specific liquid metal that is circulated and the needs of the targeted application. As stated by the authors, the high-temperature chemical compatibility between candidate structural materials and the liquid metal is a prerequisite for extreme-temperature liquid-metal pumping. This chemical compatibility must be investigated by long-term tests under variable conditions before a decision can be made about the suitability of a particular pump system. Such studies require an investment of time and resources by industry.

Amy and co-workers' pump system paves the way for technological breakthroughs that could have a substantial financial impact on technologies that use liquid metals. These technologies range from concentrated solar power, thermal-energy storage and liquid-droplet heat exchangers to gas-turbine-blade cooling and various metal-processing methods. The nuclear industry could also benefit from the authors' innovation: designing reliable pumps is key to the development and efficient operation of nuclear reactors cooled by heavy liquid metals, such as the Multi-purpose Hybrid Research Reactor for High-tech Applications[7] (MYRRHA), which is under construction. Such reactors will be instrumental in the global efforts to decrease the radiotoxicity and longevity of nuclear waste. ■

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1. Fahrenholtz, W. G. & Hilmas, G. E. *Scr. Mater.* **129,** 94–99 (2017).
2. Amy, C. *et al. Nature* **550,** 199–203 (2017).
3. Carter, C. B. & Norton, M. G. *Ceramic Materials: Science and Engineering* (Springer, 2007).
4. Lorenzin, N. & Abánades, A. *Int. J. Hydrog. Energy* **41,** 6990–6995 (2016).
5. Lambrinou, K., Charalampopoulou, E., Van der Donck, T., Delville, R. & Schryvers, N. *J. Nucl. Mater.* **490,** 9–27 (2017).
6. Barsoum, M. W. *MAX Phases: Properties of Machinable Ternary Carbides and Nitrides* (Wiley, 2013).
7. Aït Abderrahim, H., De Bruyn, D., Van den Eynde, G. & Michiels, S. in *Encyclopedia of Nuclear Physics and its Applications* (ed. Stock, R.) 689–704 (Wiley, 2013).

OBESITY

Receptors identified for a weight regulator

The discovery of the receptors for the protein GDF15 suggests that it regulates food uptake through the emergency pathway — a neuronal circuit that causes weight loss in response to cancer, tissue damage and stress. SEE LETTER P.255

MART SAARMA & ADRIAN GOLDMAN

Obesity is a serious global-health problem: more than 2 billion people are overweight, roughly equivalent to every fourth person in the world (go.nature.com/2xh1coq). This condition is a major and growing health-care burden, predisposing people to diseases ranging from osteoarthritis to cardiovascular disease. Four papers, one[1] on page 255 and three[2–4] in *Nature Medicine*, report the discovery of the receptors for a secreted protein known as growth and differentiation factor 15 (GDF15), which acts as a regulator of body weight. These receptors might serve as a biological target for therapeutics for some of the disorders that can lead to obesity.

GDF15 is a member of the large transforming growth factor-β (TGF-β) superfamily of proteins[5]. Mice that overexpress GDF15 show reduced food intake and body weight compared with wild-type mice, and do not develop obesity and insulin resistance[6],