second figure). From sediments collected at a depth of 10,898 m during this dive, Kato *et al*. (*8*) isolated two strains of obligately barophilic bacteria. Growth of these isolates was optimal between 700 and 800 atm, with no growth detected below 500 atm. From sediment samples collected at the same depth in the Mariana Trench, Pathom-aree *et al*. isolated 38 strains of actinomycetes (a group of Gram-positive bacteria) (*9*).

The few bioactive compound screening studies reported to date on deep-sea actinomycetes have yielded extraordinary results. Unique compounds isolated from an actinomycete inhabiting deep-sea sediments in the South China Sea have shown potent activities against three tumor cell lines and also showed antibacterial activities (*10*). Compounds isolated from another deep-sea actinomycete exhibited cytotoxicities against five different human cancer cell lines (*11*).

Given the ongoing scientific interest in chemosynthetic communities, questions concerning the adaptations and tolerance of barophilic organisms to extreme pressures, and the potential medical and economic interest in deep-sea microbes and other organisms (*12*), the largely unexplored ocean environments at depths greater than 7000 m are fertile grounds for scientific exploration. With Cameron's recent journey to the Challenger Deep, the world now has a new technology (see the first figure) capable of transporting humans to these extreme high-pressure environments.

References

1. M. L. Jones, *Biol. Soc. Wash. Bull.* **6**, 1 (1985).
2. R. Lutz *et al*., *Nature* **371**, 663 (1994).
3. R. A. Lutz, R. M. Haymon, *Natl. Geogr. Mag.* **186**, 114 (1994).
4. R. A. Lutz, in *Life at Extremes: Environments, Organisms and Strategies for Survival*, E. M. Bell, Ed. (CAB International, Wallingford, UK, 2012), pp. 242–270.
5. http://en.wikipedia.org/wiki/List_of_submarine_topographical_features#List_of_oceanic_trenches
6. K. Fujikura *et al*., *Mar. Ecol. Prog. Ser.* **190**, 17 (1999).
7. A. A. Yayanos, A. S. Dietz, R. Van Boxtel, *Appl. Environ. Microbiol.* **44**, 1356 (1982).
8. C. Kato *et al*., *Appl. Environ. Microbiol.* **64**, 1510 (1998).
9. W. Pathom-aree *et al*., *Extremophiles* **10**, 181 (2006).
10. S. Li *et al*., *Mar. Drugs* **9**, 1428 (2011).
11. H. Huang *et al*., *J. Nat. Prod.* **75**, 202 (2012).
12. M. M. McNeil, J. M. Brown, *Clin. Microbiol. Rev.* **7**, 357 (1994).

Published online 12 April 2012
10.1126/science.1222641

APPLIED PHYSICS

Solution-Processible Electrodes

Polymer-coated surfaces may provide a low-cost route for processing and fabricating organic-based electronic devices.

Michael G. Helander

Electronics based on thin-film organic materials offer the promise of low-cost flexible solar cells, displays, and light sources that have the potential to be manufactured on large-area plastic substrates via roll-to-roll printing techniques (*1*). These exciting applications are made possible by the relative ease of processing of organic compounds relative to traditional inorganic semiconductors such as silicon. Unfortunately, fabricating these organic-based devices is still prohibitively expensive because they require several costly vacuum-processing steps to manufacture. One of the key barriers to eliminating these steps, in order to realize a low-cost, all solution-processed device, is finding a suitable low–work function electrode material to replace the reactive metals that are typically used, such as calcium, magnesium, or aluminum. On page 327 of this issue, Zhou *et al*. (*2*) report on a general method of engineering low–work function electrode surfaces by means of polymeric surface modifiers containing simple aliphatic amine functional groups. Their method is applicable to a wide range of different electrode materials and can also be used in most state-of-the-art high-efficiency organic electronic devices, including organic solar cells, organic thin-film transistors, and organic light-emitting diodes.

Although the measurement of the work function of a material was first reported more than a century ago (*3*, *4*) as part of an observation of the photoelectric effect, new methods of engineering stable low–work function surfaces are still at the forefront of scientific discovery. The difficulty in realizing a suitably stable material is that the work function—the minimum energy required to remove an electron from the surface of a solid—scales with the electronegativity of the atoms in the bulk (*5*). As a result, low–work function materials are inherently more reactive and therefore typically require vacuum processing to prevent oxidation of the electrode contacts.

Zhou *et al*. circumvented this problem of surface oxidation by starting with more stable high–work function materials, such as gold, and then reducing the electrostatic potential at the surface [work function scales with electrostatic potential (*6*)] by adding a thin coating of polymer surface modifier. Although this approach has been used before, previous surface modifiers have relied on specific chemical interactions between the modification layer and the electrode surface, which only works for particular material combinations. In contrast, Zhou *et al*. used air-stable polyethylenimine (PEI) polymers, traditionally used for enzyme immobilization and carbon sequestration, that strongly physisorb to a wide range of different materials, including metals, oxides, polymers, and graphene. Because PEI is a cationic polymer, it strongly reduces the surface electrostatic potential when applied as a thin surface modification layer, thus lowering the work function.

The right solution. The method of polymer-modified surfaces reported by Zhou *et al*. provides the potential to manufacture low-cost solution-processed organic electronics such as an all-polymer solar cell.

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Zhou *et al*. demonstrated the utility of their method by incorporating low–work function PEI-modified electrodes into various electronic devices, including simple organic diodes, organic solar cells, organic thin-film transistors, oxide thin-film transistors, and organic light-emitting diodes. Remarkably, the performance of the PEI-modified electrodes was comparable to that of standard low–work function metal contacts in most of these devices. Even more impressive, using PEI to lower the work function of the conductive polymer PEDOT:PSS [poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate)], they fabricated an all-polymer solution-processed organic solar cell in which the substrate, anode, active layer, and cathode are

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all polymers (see the figure). Although Zhou *et al*. have made an appreciable step toward eliminating the costly vacuum deposition of low–work function metal electrodes, there is still much work to be done before low-cost roll-to-roll printing of organic electronics is fully realized.

The long-term stability and device lifetime of low–work function PEI-modified electrodes needs to be examined in various organic electronic devices. The preliminary lifetime testing data reported by Zhou *et al*. for an organic solar cell are promising, but longer-term testing on packaged devices operating under real conditions needs to be performed to ensure that the electrodes are stable for the lifetime of any commercial product in which they may be used. From a practical point of view, it is still not clear whether scale-up of solution-processing techniques for organic electronics to mass production is truly viable. For example, state-of-the-art flat-panel displays are manufactured on large-area substrates (2.2 m × 2.5 m); to date, only vacuum-processing techniques can handle such substrates with adequate uniformity, yield, and throughput time. Nonetheless, with the strong and growing momentum behind organic electronics, the present barriers to low-cost flexible devices are poised to be overcome in the near future.

References

1. S. R. Forrest, *Nature* **428**, 911 (2004).
2. Y. Zhou *et al*., *Science* **336**, 327 (2012).
3. H. Hertz, *Ann. Phys.* **267**, 983 (1887).
4. W. Hallwachs, *Ann. Phys.* **269**, 301 (1888).
5. W. Gordy, W. J. O. Thomas, *J. Chem. Phys.* **24**, 439 (1956).
6. C. Herring, M. H. Nichols, *Rev. Mod. Phys.* **21**, 185 (1949).

10.1126/science.1220829

PSYCHOLOGY

Tapping into the Wisdom of the Crowd—with Confidence

The subjective confidence of individuals in groups can be a valid predictor of accuracy in decision-making tasks.

Ralph Hertwig

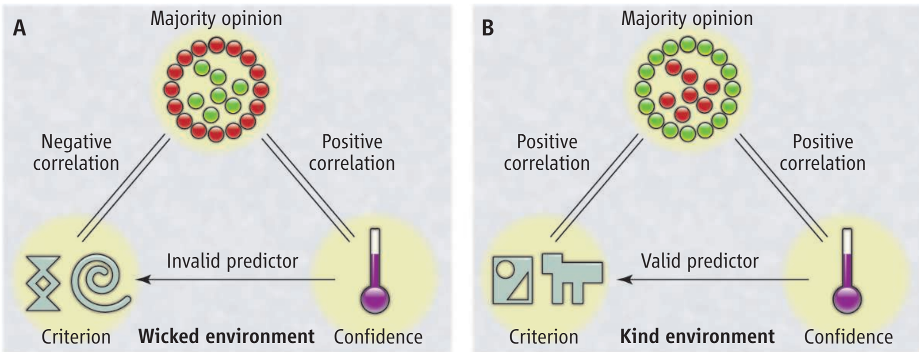
If research in psychology had a Dr. Jekyll and Mr. Hyde Award, it would go to—drum roll, please—the group as a decision-making instrument. Since the late 19th century, the group (also known as jury, team, crowd, and swarm) has been deplored as a source of intellectual inferiority (*1*) and disastrous policy decisions (*2*) and hailed as a source of near-magical creativity (*3*) and unparalleled wisdom and forecast accuracy (*4*, *5*). Some of these attributions have proved to be unfounded. For instance, with respect to creative potential, groups that engage in brainstorming lag hopelessly behind the same number of individuals working alone (*6*). The key to benefiting from other minds is to know when to rely on the group and when to walk alone. On page 360 of this issue, Koriat (*7*) explores the value of individual confidence in group decision-making.

After a medical test, the physician tells you that the results suggest a worrying abnormality. Despite the doctor's high confidence in her conclusion, you seek a second opinion. The second physician believes that the cause is probably benign. But his level of confidence is lower than the first physician's. Whose opinion should you believe?

Koriat's analysis speaks to such dilemmas. Presenting his participants with inference tasks involving two alternatives (such as which of two countries has a larger area), he shows that members of dyads—and, by extension, larger groups—can tap into the wisdom of two heads even in the absence of social interaction by using a simple heuristic: Select the response expressed with the higher—or in the case of more than two heads, highest—degree of confidence.

This maximum-confidence slating (MCS) heuristic enables humans to benefit from the presence of two or more opinions in choice tasks. Another simple and highly adaptive combination tool in choice tasks is the majority rule, but it requires at least three opinions (*8*). In estimation tasks, no combination strategy rivals the intelligent simplicity of averaging, which exploits the benefit of error cancellation (*9*).

Why and when does the MCS heuristic work? By using the subjective confidence of each judge in the accuracy of their response, the heuristic flexibly adopts the opinion of one or the other judge. It does not bet that the same person will always be the best judge (while not precluding this possibility), but rather adaptively aligns itself with the judge who produces the most confident response in a given trial. In his first two experiments, Koriat shows that using this heuristic enables a level of inferential accuracy that is substantially higher than that achieved by the dyad's higher-performing member. Furthermore, a person who responds to the same task twice, separated by an interval and thus enabling variability (for example by forgetting), can boost accuracy by select-



The role of confidence. In "wicked" environments (**A**), in which confidence correlates positively with the majority opinion (red dots) and the majority opinion correlates negatively with the criterion (correct response), confidence is an invalid predictor of the criterion. In contrast, Koriat shows that relying on the more confident response of a virtual dyad fosters accuracy in "kind" environments (**B**), in which confidence correlates positively with the majority opinion (green dots), and the latter correlates positively with the criterion.

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