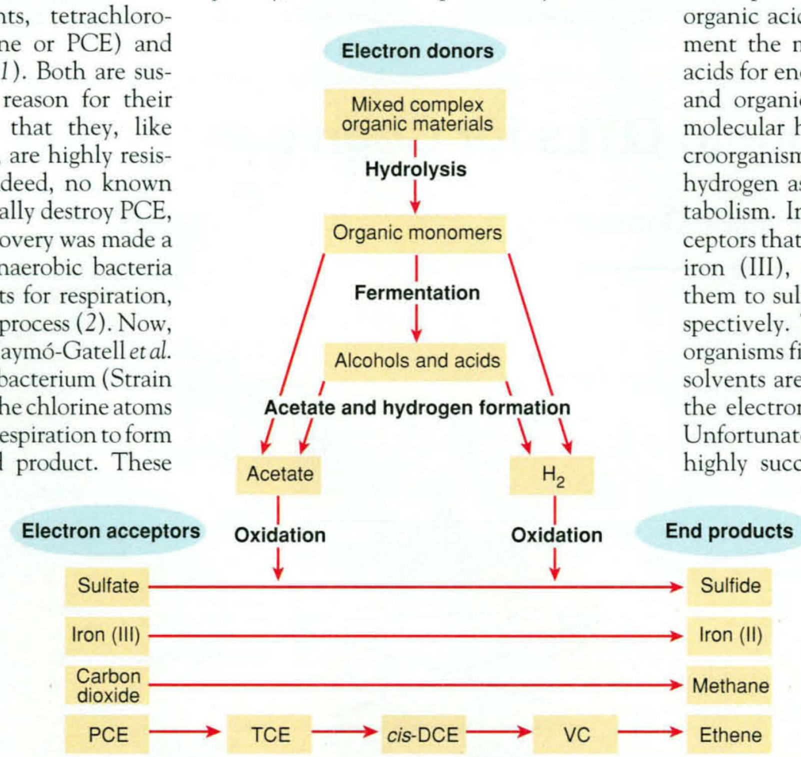
MICROBIOLOGY

Breathing with Chlorinated Solvents

Perry L. McCarty

Chlorinated solvents are effective cleaners, removing dirt and oils from clothes, engines, machines, and electronic parts. In the past, the dirtied solvents were dumped into landfills, stored in disposal tanks that often leaked, or spilled on the ground—only sometimes accidentally. As a result, the most common contaminants of organic groundwater at hazardous waste sites are the two major chlorinated solvents, tetrachloroethylene (perchloroethylene or PCE) and trichloroethylene (TCE) (*1*). Both are suspected carcinogens. One reason for their widespread persistence is that they, like other chlorinated solvents, are highly resistant to biodegradation. Indeed, no known microorganism can aerobically destroy PCE, although the surprising discovery was made a few years ago that some anaerobic bacteria can use chlorinated solvents for respiration, breaking them down in the process (*2*). Now, on page 1568 of this issue, Maymó-Gatell *et al.* (*3*) report the isolation of a bacterium (Strain 195) that can remove all of the chlorine atoms from PCE and TCE by halorespiration to form ethene, an innocuous end product. These halorespiring organisms can potentially be used to destroy chlorinated solvents naturally in the environment or in engineered treatment systems.

We rely on microorganisms to cleanse soils and waters of most natural or human-created compounds that make their way there. The chlorinated compounds are among the most troubling because of their carcinogenic hazards and their resistance to natural destructive forces in soils and water. What prevents the breakdown of these compounds? Natural reductive dehalogenation of chlorinated solvents (*4–6*) occurs when the bacteria can use the solvents as electron acceptors to generate energy for growth, similar to the way oxygen is used by aerobic organisms. In halorespiration, the chlorinated solvents are reduced through reductive dehalogenation, which is the removal of one or more chlorine atoms and their replacement with hydrogen. Bacteria that can carry out this reaction do not occur everywhere, and where they do occur they generally do not completely remove the chlorines. Frequently, PCE and TCE persist for years without change, because electron donors required for halorespiration are absent.



Detoxification: a competitive situation. Electron flow from electron donors to electron acceptors in the anaerobic oxidation of mixed and complex organic materials. Microorganisms that can use chlorinated compounds (PCE, TCE, cis-DCE, and VC) as electron acceptors in halorespiration compete for the electrons in the acetate and hydrogen intermediates with microorganisms that can use sulfate, iron (III), and carbon dioxide.

At some locations, such as sanitary landfills or waste lagoons, chlorinated solvents make up only a small portion of the total waste load. The other organics can provide the electron donors required for dehalogenation. But even in the presence of the other compounds, dechlorination of PCE and TCE is generally incomplete. They are dehalogenated to *cis*-dichloroethene (*cis*-DCE) and then to vinyl chloride (VC), a singly chlorinated ethene that is a troublesome known human carcinogen. In 1989, complete dechlorination of PCE and TCE to ethene was reported, but in mixed cultures (*7*). Now Maymó-Gatell report the existence of a bacterium that may be the responsible party (*3*).

But if these organisms that can halorespire exist in the soil, why—in groundwaters contaminated with PCE and TCE and other organics—is the conversion to ethene not complete? In cases where organic materials are present to provide the electron donors required for halorespiration, the complete destruction of PCE and TCE under anaerobic conditions involves consortia of many microorganisms working together (see the figure). Some hydrolyze complex materials to simple monomers (sugars, amino acids, organic acids), and they or others then ferment the monomers to alcohols and fatty acids for energy. Others oxidize the alcohols and organic acids, producing acetate and molecular hydrogen. A few competing microorganisms then oxidize the acetate and hydrogen as electron donors in energy metabolism. In turn, they reduce electron acceptors that may be available, such as sulfate, iron (III), or carbon dioxide, converting them to sulfide, iron (II), and methane, respectively. This is where the halorespiring organisms find their niche when chlorinated solvents are present. They also compete for the electrons in hydrogen and acetate (*8*). Unfortunately, these organisms are not highly successful in this competition and gain only a small share of the available electrons. Now that an organism that can carry out the complete conversion of PCE and TCE to ethene is available, we are in a better position to learn why they are not more effective and how we can increase their competitive advantage.

The first microorganism that was reported to use chlorinated solvents for halorespiration, *Dehalobacter restrictus* (*2*), is a strict anaerobe. It reduces PCE to TCE and cDCE while using either hydrogen or formate as electron donor for energy. The strange aspect of *D. restrictus* is that it cannot obtain energy from oxidation of any other electron donor that was examined except formate or hydrogen or use any other electron acceptors except PCE and TCE. An interesting question of high ecological significance is how such an organism with such a restricted diet could have evolved, since chlorinated solvents are such new compounds to the environment? The organism now isolated by Maymó-

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Gatell *et al.* that carries out the complete reduction to ethene has a similarly restricted diet, and the same question can be posed on its behalf.

Equally fascinating is the rapidly growing number of microorganisms now identified that are capable of the partial halorespiration of PCE and TCE to *cis*-DCE (*3*). Most are not as restrictive in their diets as *D. restrictus* and Strain 195, but can obtain energy for growth from many other electron donors and acceptors. Indeed, Strain MS-1, which can reduce PCE to *cis*-DCE while using acetate as an electron donor, can grow fermentatively on a wide variety of organic compounds and can even use oxygen or nitrates as electron acceptors in energy metabolism (*9*). These it uses first if available because of the much greater energy generation. But when they are not available or become depleted, PCE can then be used.

Several laboratories have been attempting to isolate strains that can completely dehalogenate *cis*-DCE or VC to ethene. Strain 195 is the first isolated, but undoubtedly many others with this ability exist. Whether these others will be similarly restrictive in diet remains to be seen, but it seems likely they will not, judging from the broad capability of organisms recently identified that convert PCE to *cis*-DCE. We have much to learn about how these microorganisms obtain energy through halorespiration, whether they all use similar biochemical pathways, and how the process is regulated. Some electron donors may provide a better competitive advantage for halorespiring organisms, and we need to understand why. The significant step taken by Maymó-Gatell *et al.* should help answer many of these questions about halorespiration of chlorinated solvents.

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HUMAN GENETICS

Twins: En Route to QTLs for Cognition

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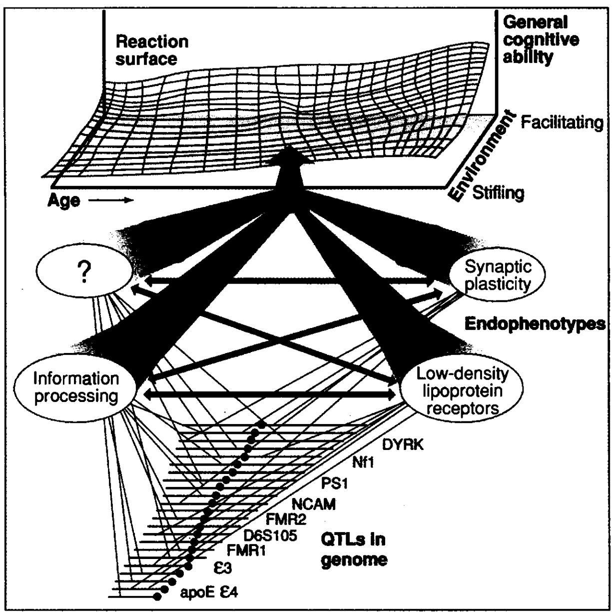
Suppose you want to measure the contribution of genes to cognitive ability. So you suggest an experiment that requires cloning human beings in order to guarantee that one of your tested groups is 100% genetically similar. Many eyebrows would surely be raised. But if truth be told, such experiments of Nature have been conducted routinely since the days of Sir Francis Galton (1875) (*1*) on identical (monozygotic) and fraternal (dizygotic) twins to study both diseases and quantitative traits [traits such as blood pressure or intelligence quotient (IQ) that vary continuously, rather than in an all-or-none manner]. Since Galton's time, the journey of behavioral geneticists from their reputation as determinists (genes determine behaviors) to the one they now strive for as probabilists (genes determine the likelihood of behaviors) has been an uphill struggle. Now, a landmark study on page 1560 of this issue marks an achievement in this struggle and reports the counterintuitive result that the genetic contribution to cognitive ability is remarkably constant throughout life (*2*).



Influence of genes, environment, chance, and time on general cognitive ability. [Adapted from Sing *et al.* (*7*)]

The U.S.–U.K.–Swedish team of researchers analyzed the cognitive abilities of an extensive sample of Swedish octogenarian twins using the classical method (that is, determination of the genetic contribution to cognition at a single time point). For these 240 intact pairs of twins, the heritability (proportion of trait variance attributable to genetic agents) of general cognitive ability is 62%, a value remarkably consistent with the value of this parameter in adolescence and onward (*3*). These data fill a gap in theories about the epigenesis of intellect over the course of life; previously it was supposed that with accumulated experience the contribution of one's genetic makeup to intellectual functioning declined; now it seems that in fact it remains rather stable.

Such cross-sectional samples of twins at single time points and their allegedly simplistic statistics have technical flaws, but nevertheless have yielded well-cited data (*1*, *4*). The flaws in this approach can be captured in the words of the physicist P. Hansma (*5*, p. 1882), who was contrasting electron microscope images of RNA with the dynamic creation of enzymes: [Heritabilities are] "like snapshots of a ballerina. They won't tell you about the ballet." As a consequence of this shortcoming, current practitioners, including the authors of the new study, have already moved from this classical approach to multitime point, longitudinal designs and to the hunt for QTLs (quantitative trait loci), both of which are required to complement the classical strategies for understanding complex traits (*6*).

The new data complement existing evidence for the strength of genetic influences on cognition. The correlational similarity of various indicators of general cognitive ability, sometimes referred to as g, has been assessed for pairs of relatives ranging from 0 to 100% gene overlap and from 0 to 100% environmental overlap. An overview of these data (*3*) indicates that genetic agents ac-

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