nderlie the discrepancy concerning pro-
active facilitation.

It might also be argued that the drug was operating on consolidation proc-
esses. Since it is generally assumed that consolidation is a progressive stabiliza-
tion of a memory trace over time, our data suggest that this labile phase of
memory lasts for at least 5 days. That there was a trend toward facilitation in
the LD(1) group supports this conten-
tion. The same trend, however, ap-
ppeared in the LD(5) group. Thus we
would have to postulate not only that the labile phase persists for at least 5
days, but also that there is equipotentiality of the memory trace throughout this
time period. These assumptions are not supported by previous investigations,
which found no evidence of retrograde facilitation of memory when the drug
was administered at intervals beyond
several hours after training (1–3). Fur-
thermore, the consolidation argument
can be vitiated since neither the LD(1)
nor the LD(5) group differed signifi-
cantly from the control group in this
study.

It is conceivable that the observed facilitation could be attributable to
performance factors unrelated to mem-
ory. For instance, the repeated drug
administration could have increased
motivational, arousal, or attentional
levels. Further, activity levels as well
as sensitivity to the white and dark
alleys could have been altered. If, how-
ever, any of these variables were re-
 sponsible for the reported enhancement,
it is likely that the naive groups given
strychnine would have been similarly
facilitated.

Since strychnine was facilitating only
to animals that had received prior ex-
posure to the maze, the most reason-
able interpretation of these results is
that strychnine influenced the long-term
store of memory. There are several
ways in which strychnine could have
produced the observed enhancement.
The drug could have strengthened the
informational representation of the
training experience or could have re-
tarded the decay of that representa-
tion from the long-term store (preven-
tion of forgetting). Alternatively, stry-
chnine may have increased the accessi-
bility of information in the long-term
memory store (enhancement of retrieval
processes). At present, these alternatives
cannot readily be distinguished. It
should be noted that some investigations
of facilitation of memory have em-
ployed repeated administrations of the
analectic compound over many days.

The facilitation observed in some of
these studies may be due in part, there-
fore, to the enhancement of the long-
term store of memory. Finally, the most
significant finding of this research is
that the long-term store of memory is
dynamic and susceptible to pharmaco-
logical manipulation.

HERBERT P. ALPERN

JOHN C. CRABBE

Department of Psychology and
Institute for Behavioral Genetics,
University of Colorado, Boulder 80302

References and Notes

Neurobiol. 8, 139 (1965); J. L. McGaugh, Science
153, 1351 (1966); E. R. John, Mechanisms of Memory
(Academic Press, New York, 1967); J. L. McGaugh, in Psycho-
PHS Publ. 1836 (Government Printing Office, Wash-
ington, D.C., 1968), pp. 891-904; —— and R. G. Dawson,
Behav. Sci. 16, 45 (1971).

2. W. Park, J. Comp. Physiol. Psychol. 54, 506
(1961); J. L. McGaugh, W. Westbrook, C. W. Thomson,
ibid., 55, 710 (1962); B. Doty and L. Doty, Psychopharmacologia 9,
234 (1966); J. A. Kivrakene and J. L. McGaugh,
ibid., 12, 303 (1968); Agents and Actions 1,
36 (1969); J. L. McGaugh and J. A. Kivrakene,

3. C. P. Duncan, J. Comp. Physiol. Psychol. 42,
32 (1949); S. E. Glickman, Psychol. Bull. 58,
218 (1961); C. S. Pearlman, S. K. Sharpless,
M. E. Jarvik. J. Comp. Physiol. Psychol. 54,
Physiol. 24, 259 (1962); H. P. Alpern, D. P.
Kimble, J. Comp. Physiol. Psychol. 63, 168
(1967); ——. J. L. McGaugh, ibid., 65,
265 (1968).

4. This imbed strain is our standard laboratory
stock and has been used in other investiga-
tions of memory (D. Bosret, P.
Bovet-Nitti, A. Oliverio, Science 163, 139
(1969); C. Randi, D. Quartermain, M. Gold-
stein, B. Aragonne, ibid., 172, 49 (1971));
H. P. Alpern and J. G. Marriott, Behav.
Biol., in press.


6. Although some animals reached criterion in
less than 4 days, all were tested for at least 4
days to provide sufficient data for examin-
ing learning curves (see Fig. 1).

7. The LD₅₀ of intraperitoneally injected strych-
nine sulfate for C57BL/6 female mice (60
to 90 days old) maintained in our animal
colony is 2.5 mg/kg.

8. Latency on the first retention day varied signifi-
cantly among groups (F = 4.76, d.f. =
5,100, P < 0.01). All of the groups that re-
ceived strychnine displayed shorter latencies
than the control group; however, latencies
did not correlate with either error measure
and, consequently, were not further analyzed.

9. B. J. Winer, Statistical Principles in Experi-
mental Design (McGraw-Hill, New York,
1962).

10. B. LeBouef and H. Pecke, Psychopharma-
cologia 16, 49 (1969); H. Pecke, B. LeBouef,
M. Hertz, ibid., 263 (1971); D. Stein,
Commun. Behav. Biol. 6, 335 (1971).

Psychol. 77, 521 (1972).

12. We thank J. F. Nugent III for assistance in
testing the animals. Supported by NIMH
grants MH 11167 and MH 20574-01 and the
National Institute for General Medical Sci-
ences grant GM 15457.

21 March 1972; revised 1 May 1972

Atmospheric Circulation of DDT

In their article “DDT in the bio-
sphere: Where does it go?” Woodwell
et al. (1) present an admirable review
of knowledge about the storage and
transport of DDT [1,1,1-trichloro-2,2-
bis(p-chlorophenyl)ethane] and a math-
ematical model to describe its move-
ments. They conclude that DDT is
ultimately stored in the depths of the
ocean after evaporation into the atmo-
sphere, transference from the atmosphere
to the ocean primarily by rainfall, and
subsequent movement downward in the
ocean, until dispersed.

The model as presented necessarily
requires many assumptions, and the
validity of their conclusions must be
questioned on the basis that measure-
ments of atmospheric concentrations of
DDT, as judged by the one reference
given on the subject (2), are completely
incompatible with the requirements of
the model. In order that DDT be trans-
ported as proposed, Woodwell et al.
calculate that a worldwide circulation
of DDT components, largely as vapor,
must be present at a concentration of
80 ng per cubic meter of air, with a
mean residence time of 4 years. These
estimates are of course approximate,
and local deviations could be expected
with higher concentrations in the vicin-
iety of areas where DDT is being ap-
plied and lower values in areas where
cleaning of the atmosphere is occur-
ing. Stanley et al. (2), in a survey of atmo-
spheric concentrations, found maximum
values at various locations in the
range of 10 to 2000 ng of total
DDT components per cubic meter of
air, apparently largely particulate in
nature and related to local applications.
The background level, however, can
hardly be more than the 2 ng/m² ob-
servable repeatedly at one location
(Dothan, Alabama) where significant
agricultural applications are reported,
or the 10 ng/m² maximum observed at
the Salt Lake City site. In about 20
percent of the measurements of Stanley
et al., the concentration of DDT was
less than the detectable limit of 0.1
ng/m³ (p,p'-DDT). If there is a long-
term, worldwide circulation, it must be
at a level which is not more than 10
percent, perhaps much less than 1 per-
cent, of the predicted value. Even at
this level of accuracy, the results could
perhaps be considered a tribute to the
general analysis made by Woodwell and

724

SCIENCE, VOL. 177

Downloaded from http://science.sciencemag.org/ on January 27, 2018
his co-workers, but the results are far from sufficient to justify the conclusion that most of the DDT ever present is being transported to the ocean as proposed. From the rest of the arguments given, it would be necessary to conclude that this is at most a small part of the answer to the question of where the DDT eventually goes. If, as they suggest, an appreciable fraction of the pesticide applied is initially evaporated into the air, then the low concentration observed requires that the mean residence time in the atmosphere is too short to permit one to speak of a worldwide circulation. Woodwell’s earlier analogy (3) to the dispersal of pollen, where only a small fraction of the total material is dispersed on a global scale, would seem far more appropriate. The remaining material must either be destroyed in the atmosphere in some manner or be rapidly returned to earth to be destroyed, stored, or transported in some manner not accounted for in the model as presented.

At this point in time, it would be unreasonable to question that the use of DDT has done a great deal of good, protecting men and animals from insect-borne diseases and permitting increased production of food, or that it has also done harm, mostly by virtue of its ability to reduce the insect population, which is an important level in the food chain of wildlife, and also by virtue of its direct toxicity to fish and other species. These disadvantages are shared to a greater or lesser degree by any form of insect control. It is quite a different matter, however, to assert that the accumulation of DDT with continued usage is “causing spectacular declines in populations” of various species. If there is serious factual evidence that this is so, it would be appropriate for the authors to cite it separately from the many items of speculation, suggestion, and opinion which were provided (4).

CLARE A. STEWART, JR.
407 Brentwood Drive, Carr croft,
Wilmington, Delaware 19803

References and Notes
4. References cited in this regard include, for example, a generalized discussion by Woodwell (5) and the report of a study committee (5), Woodwell participating. These present much the same opinions but no evidence with any obvious bearing on this issue.

The decay and transfer rates that we used in our analysis were derived from the literature as explained in detail in the article. The set of rate constants that appeared most reasonable to us resulted in a prediction of a peak DDT concentration in the atmosphere of about 80 ng per cubic meter of air in 1966. The data of Stanley et al. (1) appear to support our analysis in that concentrations of DDT in samples of air of nine U.S. cities in 1967-1968 commonly fell in the range from 1 to 100 ng of DDT residues per cubic meter of air, as we mentioned in our article. This span was obtained not from the table of maxima as Stewart asserts, but from a consideration of all of the data presented. Stanley et al. moreover found p,p'-DDT and o,p'-DDT in all localities and considered “typical” concentrations of DDT residues in air to be 10 to 30 ng/m³. Their report contains no explicit basis for the assertion of Stewart that “In about 20 percent of the measurements... the concentration of DDT was less than the detectable limit of 0.1 ng/m³.” The data from Dothan, Alabama, which Stewart prefers, include only concentrations of p,p'-DDT, which may be from one-half to two-thirds of the total DDT residues as judged from other data presented. Fourteen selected analyses were presented for Dothan, spanning a range from 1.3 to 7.2 ng of p,p'-DDT per cubic meter of air. These might reasonably be interpreted as indicating a range of 2 to 12 ng of total residues per cubic meter of air, in partial support of Stewart's argument that “background levels” were lower than predicted.

The rates in greatest question in our model are the rate of transfer of DDT from the troposphere to the oceans and the rate of decay of DDT in the troposphere. Time constants (τ) of several months to 1 year for the transfer of DDT from the troposphere to the oceans and of up to 2 years for the decay of DDT in the troposphere, if used in conjunction with a combined time constant for loss from the land by decay and vaporization of 3.6 years, give concentrations in the troposphere in 1966 in the range from a few to about 15 ng/m³. This modification scarcely invalidates the model; it shows its usefulness.

The fact of worldwide aerial transport of DDT residues seems hardly open to serious question. For the aerial worldwide pathway to be trivial as Stewart and others seem to wish, a small fraction of the DDT used would have to find its way into the atmosphere and its residence time in the atmosphere would have to be days as opposed to weeks, months, or years. This conclusion follows both from our analysis and from data on the rate of movement of radioactive fallout, which have shown that air parcels move around the world in mid-latitudes in 3 weeks to 1 month. Small radioactive fallout particles in the troposphere have a half-time of residence of 2 to 6 weeks (2). A careful reading of our article and the literature we cited should convince Stewart and others that the evidence at present strongly favors the idea that aerial transport is the major mechanism of worldwide transport for DDT residues. Nonetheless, there is an extraordinarily large gap here in our knowledge of the biosphere which should be embarrassing both to the purveyors of pesticides and other toxins and to those who chart the course of science.

Stewart's final comment on the effects of DDT seems to have been covered adequately in his own first two paragraphs. Our documentation of effects was more substantial than he acknowledges, and we refer him to the citations included in the article.

G. M. WOODWELL
Department of Biology, Brookhaven National Laboratory, Upton, New York

P. P. CRAIG
Department of Physics, Brookhaven National Laboratory, and Energy Program, National Science Foundation, Washington, D.C.

H. A. JOHNSON
Department of Medicine, Brookhaven National Laboratory

References and Notes
3. Research at Brookhaven National Laboratory is carried out under the auspices of the AEC.

5 July 1972
Atmospheric Circulation of DDT
Clare A. Stewart Jr., G. M. Woodwell, P. P. Craig and H. A. Johnson

Science 177 (4050), 724-725.
DOI: 10.1126/science.177.4050.724