# MANPOWER IN HIGH ENERGY PHYSICS

*By Charles H. Braden, Jerome H. Fregeau, and Glenn M. Frye, Jr.*

ONE of the important questions repeatedly raised by various scientific advisory panels and by the Congress has been that of the scientific manpower required for high-energy physics. Concern has been expressed that the "glamour" of high-energy physics and the large amounts of money being spent were attracting an excessive number of people away from other worthwhile areas of basic research or from necessary work in applied science and in defense laboratories.

The study of the elementary particles is perhaps the most rapidly expanding frontier in physics today. Within a two-year period, four new accelerators will come into operation in the United States, trebling our national capacity for experimentation in the multi-Bev region. The 30-Bev proton alternating gradient synchrotron at the Brookhaven National Laboratory began operation in the summer of 1960, the 6-Bev Cambridge electron accelerator at Harvard is scheduled for completion in 1961, the 3-Bev Princeton-Pennsylvania accelerator for protons at Princeton also in 1961, and the 12-Bev proton zero-gradient synchrotron at the Argonne National Laboratory in 1962. In addition, two further accelerators of the "next generation" are in the advanced stages of design, although their construction has not as yet been authorized. These are the two-mile linear electron accelerator at Stanford, which will initially give a 30-microampere beam at 10–20 Bev, and a synchrotron of the fixed-field alternating-gradient type, designed by the MURA group, which will yield a 30-microampere beam of protons at 10–15 Bev. These last two accelerators would be among the most expensive scientific instruments ever built, each costing over $100 million for construction and requiring an annual operating budget of $15–20 million upon completion.

To provide a quantitative answer to the questions about manpower, a survey was made in early 1960 by the various government agencies which support research in high-energy physics. These are the Atomic Energy Commission, the National Science Foundation, the Office of Naval Research, and the Air Force Office of Scientific Research. The survey was coordinated by the Technical Committee on High-Energy Physics of the Federal Council on Science and Technology. In the survey, we attempted to: (1) determine the number of professional level people now involved in high-energy physics research, high-energy nuclear chemistry research, and accelerator design and construction, and (2) determine the anticipated change in these numbers for the next five years.

An intensive effort was made to contact every university which has a high-energy program or which has expressed an interest in starting such a program in the next few years. The questionnaire was sent directly to the university or national laboratory unless the information was already available at one of the government agencies. Questions were also asked on the number of engineers, technicians, and support personnel required in the national program, but these data will not be pre-

This article was prepared jointly by three physicists associated with agencies of the federal government in Washington, D. C.: C. H. Braden, associate program director, Physics Program, National Science Foundation (on loan from Georgia Institute of Technology); J. H. Fregeau, physicist, Nuclear Physics Branch, Physical Sciences Division, Office of Naval Research; and G. M. Frye, Jr., Physics and Mathematics Branch, Division of Research, Atomic Energy Commission (now at Case Institute of Technology). The opinions expressed in their article are those of the authors and do not necessarily represent the official positions of their agencies.

NO. 21

EPR AT WORK SERIES

# HYPERFINE STRUCTURE IN ORGANIC FREE RADICALS BY EPR

(ELECTRON PARAMAGNETIC RESONANCE)

**Interaction in organic free radicals of the unpaired electron with the magnetic moments of the protons frequently gives rise to well defined hyperfine structure. Often this structure permits identification of an unknown radical. One may also extract detailed information on electron wave functions from this observed hyperfine splitting.**

## EXAMPLE

**Tetracene positive ion free radical.**

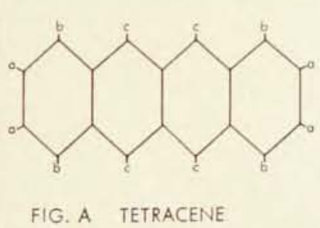


FIG. A TETRACENE

Tetracene, Figure A, when dissolved in concentrated $H_2SO_4$ forms a positive ion free radical, which has been investigated with EPR by Weissman and others[1]. We recently reexamined this radical[2] using the high sensitivity Varian 100 kc EPR spectrometer. Figure B shows the total spectrum and Figure C, the seven central lines obtained with a slower scan of the DC magnetic field. The temperature was 65°C and the concentration, $10^{-4}$ molar.

The resonance saturates easily, and the V-4500-41A low-high power bridge was therefore necessary to permit observation at 30 db attenuation of the klystron power (0.20 mw at the sample). All lines are 60 milligauss peak-to-peak, and the line width is independent of temperature. When using 100 kc field modulation one expects resonance sidebands to occur at ± 30 milligauss from the line center, and it is felt that these sidebands determine the observed line width. Work of this type requires good magnetic field

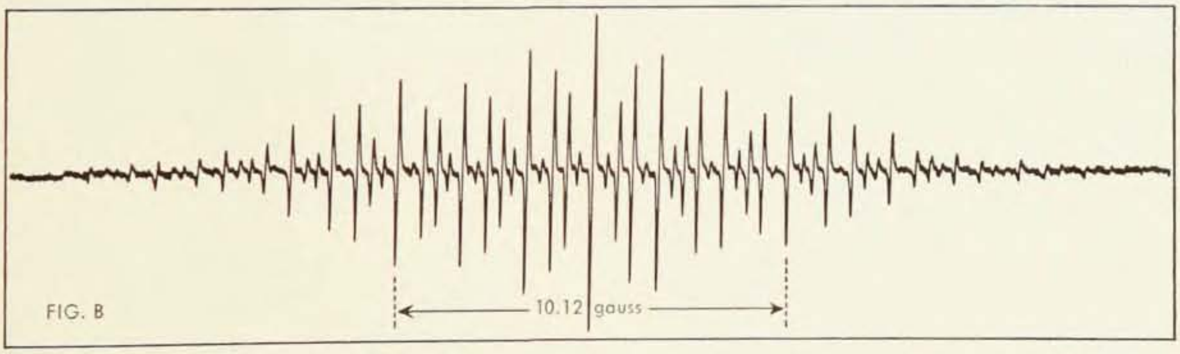


FIG. B

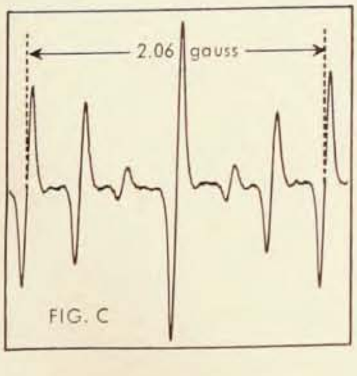


FIG. C

homogeneity and magnet power supply stability. A Varian 12″ rotating magnet and regulated power supply were used.

The spectrum may readily be reconstructed. From Figure A it can be seen that there are three classes of protons, a, b and c, with four protons in each class. Four identical protons give rise to five energy levels with degeneracies of 1, 4, 6, 4, 1, and three such groups of 4 give rise to $5^3$, or 125 lines with easily determined relative intensities. In fact, we find one of the splittings is within 1% of being three times another, which results in 85 lines, 81 of which can be seen in the figure. The three splittings are 1.03 gauss, 1.69 gauss, and 5.06 gauss. Calculated intensities agree closely with experimental values.

[1] *S. I. Weissman, E. DeBoer and J. J. Conradi, J. Chem. Phys.* ***26****, 963 (1957); E. DeBoer and S. I. Weissman, J. Am. Chem. Soc.* ***80****, 4549 (1958); A. Carrington, F. Dravnieks and M. C. R. Symons, J. Chem. Soc. 947, (1959).*

[2] *H. W. Brown and J. S. Hyde, (to be published).*

Table I. Numbers of Individual PhD Scientists in High-Energy Research and Accelerator Construction

(*Equivalent man-years are listed in parentheses.*)

| | *1959–60* | *1960–61* | *1962–63* | *1964–65* |
|---|---|---|---|---|
| A. Experimental High-Energy Physics | | | | |
| Universities Without Accelerators | 123 (74) | 160(105) | 210(140) | 250(180) |
| Universities With Accelerators | 144(101) | 160(115) | 190(130) | 210(150) |
| Argonne, Brookhaven, and Berkeley | 119 (92) | 150(125) | 220(170) | 240(200) |
| Totals: | 386(267) | 470(345) | 620(440) | 700(530) |
| B. Theoretical High-Energy Physicists | 229(149) | 280(190) | 370(250) | 430(300) |
| C. High-Energy Nuclear Chemistry | 35 (22) | 40 (25) | 50 (30) | 50 (40) |
| D. Accelerator Design & Construction | 103 (86) | 120(100) | 140(130) | 130(120) |
| Total Doctoral Level Scientists | 753(524) | 910(660) | 1180(850) | 1310(990) |

sented. It may be noted that the trend in these categories does not differ significantly from the trends reported here.

A list of definitions, admittedly somewhat arbitrary, accompanied the questionnaire in an attempt to obtain uniformity in categories which are subject to varying interpretations. The pertinent definitions are: (1) a *high-energy accelerator* is defined as one which produces mesons; (2) *theoretical high-energy physics* includes subjects such as elementary particle theory, meson scattering analysis, nucleon and electron scattering above 300 Mev, strange particle theory, etc. The theory of nuclear structure is excluded; (3) an *individual* is considered to be engaged in high-energy physics, if he spends over 10% of his productive effort during a year in this field; and (4) a *PhD candidate* is a graduate student who has reached the level where he is ready to begin his thesis research.

As a general guide in estimating future manpower needs, the recipients of the questionnaire were asked to assume that the course of high-energy physics would follow the recommendations of the Joint Panel on High-Energy Accelerator Physics of the President's Science Advisory Committee and the General Advisory Committee to the Atomic Energy Commission (PSAC/GAC, or the "Piore Panel"). These recommendations were that existing accelerators and those under construction be funded at an adequate level for their effective utilization. The Panel further recommended that the Stanford accelerator be authorized immediately and that a high-intensity proton accelerator above 8 Bev be built, as well as other smaller accelerators. Since projects in this "new construction" group will not be operating until after 1965, their only influence on the manpower totals is in the accelerator design and construction category.

In 1959–60, government support of high-energy physics amounted to $80 million. To support the program outlined above, it is estimated that the annual rate for carrying out this program including construction, operation, and research would be about $200 million per year by 1965.

## *Results of the Survey*

THE numerical results of the survey for the last year for which definite figures are available, 1959–60, and the estimates for the present year of 1960–61 and the two future years of 1962–63 and 1964–65 are presented in Tables I and II. No attempt was made to estimate the uncertainty in the figures. Some of the significant trends are:

### (a) *Experimental High-Energy Physicists*

The number of PhD physicists engaged in research in high-energy physics is expected to increase from 386 in 1959–60 to 700 in 1964–65. This approximate factor of two increase is maintained in a breakdown into the following three categories: (1) at universities which do not have an accelerator, the increase will be from 123 to 250, (2) at universities which have or will have high-energy accelerators (including the Cambridge electron accelerator and Princeton), the increase will be from 144 to 210, (3) the three largest high-energy laboratories (Argonne, Brookhaven, and Berkeley) will enlarge their permanent staffs from 119 to 240 with the largest jump coming at Argonne where high-energy physics was just beginning in 1959–60, but where the ZGS will be in operation by 1962.

### (b) *Theoretical High-Energy Physicists*

The number of PhD's in theoretical high-energy physics also roughly doubles, going from 229 in 1959–60 to

Table II. Numbers of PhD Candidates in High-Energy Research and Accelerator Construction

| | *1959–60* | *1960–61* | *1962–63* | *1964–65* |
|---|---|---|---|---|
| Experimental Physics | 287 | 335 | 470 | 550 |
| Theoretical Physics | 155 | 200 | 290 | 360 |
| Accelerator Design & Construction | 14 | 20 | 20 | 20 |
| Nuclear Chemistry | 14 | 15 | 20 | 30 |
| Totals: | 470 | 570 | 800 | 960 |

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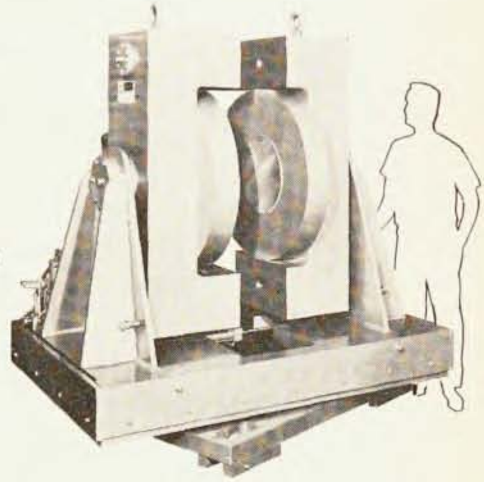
**MAGNET 16A-HI**

**11.0 KG at 3 1/8" gap with 16" diameter tips (9KW power).** Maximum power of magnet: 9KW. Vertical rotation: 360° with 0.1° vernier. Vertical adjustment: 6". Base for track mounting. Horizontal rotation available. Adjustable gap to your specifications. POWER SUPPLY: 9KW, regulation $10^5$. Homogeneity: $10^5$.

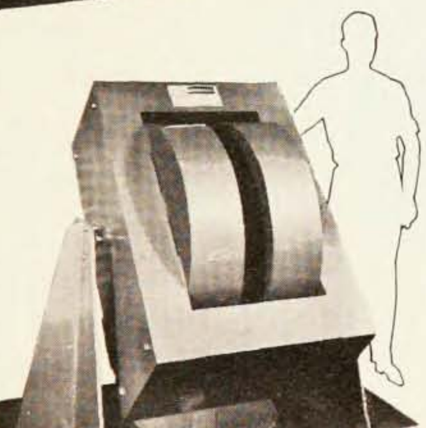
**MAGNET 15A-LI**

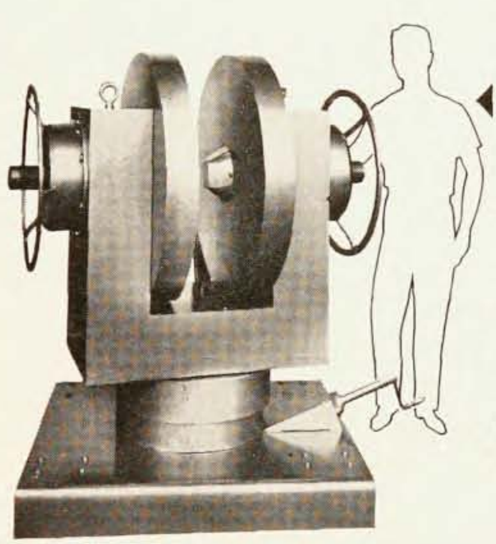
**30.0 KG at 1" gap with 15" diameter tips (80KW power). 23.0 KG at 4" gap with 15" diameter tips (80KW power). 17.0 KG at 7" gap with 15" diameter tips (80KW power).** Maximum power of magnet: 250KW. Low impedance power coils with high impedance trim coils. Maximum gap: 16". Vertical and horizontal rotation. Hydraulic opening and closing of yoke. POWER SUPPLIES: available on request.



**MAGNET 12A-HI-A**

**28.0 KG at 1" gap with tapered tips (9KW power). 20.0 KG at 1" gap with 12" diameter tips (9KW power). 11.0 KG at 4" gap with 12" diameter tips (9KW power).** Maximum power of magnet: 9KW. Vertical and horizontal rotation with 0.1° vernier. Adjustable gap: 1", 2", 4", or to specification. POWER SUPPLY: 9KW, regulation $10^5$. Homogeneity: $10^5$. Other special features on request.



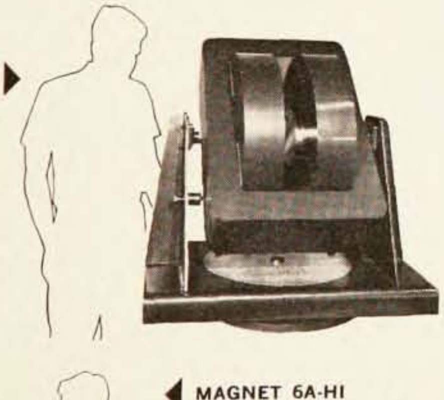


**MAGNET 12C-AT-LI-E**

**43.0 KG at 1/2" gap with 2 13/16" diameter tips (60 KW power). 38.5 KG at 1" gap with 2 13/16" diameter tips (60KW power). 17.5 KG at 5 1/2" gap with 2 13/16" diameter tips (60 KW power). 14.0 KG at 8" gap with 8" diameter pole (60KW power).** Maximum power of magnet: 100KW. Maximum gap: 8". Vertical adjustment: 6". 360° rotation about vertical axis with 0.1° vernier. 3 sets of tips furnished. Base for track mounting. POWER SUPPLY: Available on request.

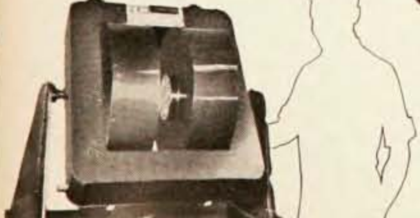
**MAGNET 8A-HI**

**13.3 KG at 2" gap with 6" diameter poles (5KW power). 12.3 KG at 2" gap with 8" diameter poles (5KW power). 8.0 KG at 4" gap with 8" diameter poles (5KW power).** Maximum power of magnet: 7KW. Vertical and horizontal rotation with 0.1° vernier. Adjustable gap: 1", 2", 4", or to specification. POWER SUPPLY: 7KW, regulation $10^5$.



**MAGNET 4A-HI**

**10.5 KG at 1" gap with 4" diameter tips (2.4KW power). 4.6 KG at 4" gap with 4" diameter tips (2.4KW power).** Maximum output of magnet: 2.4KW. Adjustable gap: 1", 2", 4", or to specification. Vertical and horizontal rotation with 0.1° vernier. POWER SUPPLY: 2.4KW, regulation $10^5$.



**MAGNET 6A-HI**

**14.0 KG at 1" gap with 6" diameter poles (7.5 KW power). 10.5 KG at 2" gap with 6" diameter poles (7.5KW power). 6.3 KG at 4" gap with 6" diameter poles (7.5 KW power).** Maximum power of magnet: 7.5 KW. Vertical and horizontal rotation with 0.1° vernier. Adjustable gap: 1", 2", 4", or to specification. POWER SUPPLY: 7.5KW, regulation $10^5$.

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430 in 1964–65. In contrast to the experimentalists, only 19 of these in 1959–60, increasing to 40 in 1964–65, are employees at the three large laboratories. All of the rest are affiliated with a university.

(c) *Accelerator Design and Construction*

The number of PhD physicists, both experimental and theoretical, engaged in accelerator design and construction increases from 103 in 1959–60 to 140 in 1962–63 and then levels off. The increase is predominately due to the staff required for the Stanford linac and the high-intensity proton synchrotron. The increase is no larger because the four accelerators now under construction are being completed during this period and the decline in their construction staffs almost compensates for the construction staffs needed for the new accelerators.

### *Conclusion*

THE results of this survey show that the number of PhD scientists required in the field of high-energy physics, if the recommendations of the PSAC/GAC Panel are followed, is expected to nearly double from 753 in 1959–60 to 1310 in 1964–65. Thus approximately 110 additional PhD's will be needed each year, which is to be compared with the present rate of production of about 500 per year and a projected rate of 700 per year by 1965 (estimated by National Science Foundation Staff). During the same five-year period, about 1200 PhD's will be trained in high-energy physics, so that less than half of these will be required to staff the expanded high-energy program while the remainder will be available for industrial, governmental, or full-time teaching positions. It is likely, therefore, that high-energy physics will not become a sink for our top-level scientific manpower, but rather a source which will return a dividend of people trained in one of the most fundamental branches of scientific research.

It is interesting to note in this connection that even though the sites for high-energy experimentation are necessarily becoming more and more centralized as a result of the increasing size of the accelerators, the university experimental groups are continuing to be important participants. In fact, the universities without accelerators anticipate the largest growth in the number of experimentalists in the next five years. It would appear that physicists have learned to accept the inconveniences of doing their experiments at a site away from their home laboratory at an accelerator which operates on an inexorable 24-hour schedule.

The theorists working in high-energy physics will remain primarily associated with the universities. For both the theorists and experimentalists the ratio of the number of persons working in the field to the number of man-years expended remains essentially constant over the five-year period, indicating that the percentage of time devoted to teaching and other nonresearch functions is not expected to change significantly.