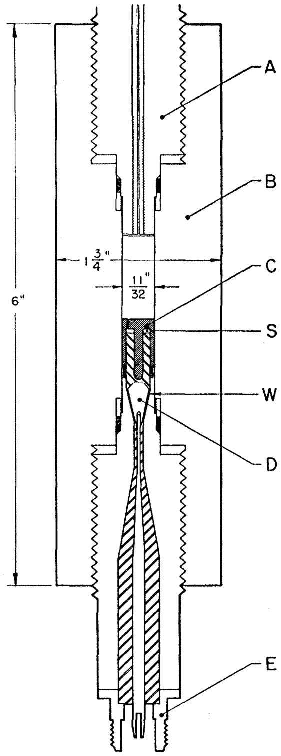

FIG. 2. High-pressure bomb and microwave transmission plug. *A*—pressure feed plug; *B*—BeCu bomb; *C*—microwave cavity; *D*—sealing cone; *E*—type *N* connector; *S*—sample position; *W*—synthetic mica washer.

both the compressibility and the thermal expansion in order to test these explanations quantitatively.

Since this is, to our knowledge, the first electron spin resonance experiment performed under high pressure, a description of the microwave coupling into the high-pressure region is given. Details of the high-pressure generating and measuring equipment are available in the literature.[8,9] The complete assembly shown in Fig. 2 consists of a nonmagnetic, BeCu cylinder with a pressure feed plug threaded into one end with a Bridgman sealing system[6] and a microwave transmission plug similarly connected at the other end. The plugs are also hardened BeCu. The microwave connection starts at a standard, 50-ohm, connector followed by a constant, 50-ohm, impedance line which tapers to 0.100 in. o.d. The line then tapers up to 0.250 in. o.d. with a BeCu cone serving as the center conductor. The cone seats on a synthetic mica ($KMg_3AlSi_3O_{10}F_2$) washer. This cone and washer assembly constitute the pressure seal for the coaxial line. The brass microwave resonant cavity is press fitted on the end of this open circuited transmission line. The cavity is coaxial, with a center stub $\sim n/4$ long (T.E.M. mode). The coupling to the transmission line is capacitive and is adjusted by changing the gap between the center stub and the cone. This type of coupling concentrates the microwave electric field in the coupling region and thus permits rather large paramagnetic samples to be placed at the shorted end of the cavity without prohibitive dielectric losses. The remaining volume of the cavity and the transmission line are filled with Teflon. The loaded Q of the cavity, monitored by sampling the reflected microwave power, is about 500. The cavity is immersed in the pressure transmission fluid, petroleum ether, thus requiring no mechanical strength of the cavity and ensuring that the paramagnetic sample is subject to purely hydrostatic pressure.

We gratefully acknowledge the assistance of Dr. G. B. Benedek of this laboratory in the design of the high-pressure system. We also wish to thank Dr. J. W. Meyer of Lincoln Laboratory for the crystal of $NiSiF_6 \cdot 6H_2O$ used in the experiment.

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† General Electric Company Fellow.

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The Convergatron, a Neutron Amplifier

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NEUTRON sources for power production or research may be divided into three categories: (a) divergent chain reactions, (b) accelerators, and (c) accelerators with amplifying targets (a convergent chain reaction). Accelerators have limited neutron output, whereas inadequate control of the divergent chain reaction may lead to a destructive excursion.

By introducing a series array of neutron-amplifier stages, it is possible to operate an arbitrarily large neutron source as a subcritical system without fear of destructive excursion by means of a small controllable primary source.

The Convergatron is a neutron amplifier consisting of three zones per stage: fissionable fuel zone (with or without moderator), a thermal neutron barrier, and a neutron moderator zone. If arranged in a series sequence the polar properties permit neutron flow from fuel through the barrier and moderator to the next fuel zone. Neutrons moving in the reverse direction are moderated and absorbed by the thermal neutron barrier so that flow is inhibited.

If each Convergatron stage has characteristics approaching a critical multiplying system, the neutron

TABLE I. Percentage of critical fuel thickness for a given amplifier gain.

Gain	Moderator thickness 50 cm D_2O	25 cm D_2O	12.5 cm D_2O
1	98.2	95.0	88.0
2	99.1	97.5	93.5
5	99.6	99.0	97.5
10	99.8	99.5	98.8

chain will converge to the sum $1/(1-k)$, where k is the effective multiplication factor for the system. A gain per stage greater than unity can be achieved by proper choice of moderator and fuel zones. The gain per stage without feedback is $g_0=\alpha p_0/(1-k)$, where p_0 is the probability of moderator penetration and α is the probability of fast-neutron escape to the next stage.

Transport theory[1,2] has been applied by Michael[3] to an infinite slab geometry using two velocity groups and distinguishing only between forward and backward motion of the neutrons. Results for D_2O moderator and pure U^{235} fuel are given in Table I. Critical fuel thicknesses were calculated to be 5.5, 5.75, and 5.95 cm U^{235} for 50, 25, and 12.5 cm D_2O.

Feedback is inherent in this system and must be strictly limited. Single-stage feedback gain is given by $g'=\alpha p_0/(1-k-\alpha\beta p)$, where β is the ratio of feedback neutron current to the preceding stage to output to the succeeding stage and p is the probability of useful capture of a feedback neutron in the fuel zone.

Feedback effects in previous stages must become increasingly small or the system will diverge. Second-stage feedback gain is given by $g''=\alpha p_0/(1-k-\alpha\beta p)+1/(1-g_0g'e^{-\sigma x}\beta)-1$, where $e^{-\sigma x}$ represents the attenuation of epithermal neutrons per stage. The requirement for stability is $\beta e^{-\sigma x}\ll g_0g'$, so that the product $g_0g'e^{-\sigma x}\beta$ is small compared to unity.

Kinetic behavior of a series array may be represented by slightly modified Bateman equations.[4]

$$d\phi_i/dt=g_0\lambda\phi_{i-1}-\lambda\phi_i,$$

$$\phi_i=g_0{}^i\phi_0\left[1-e^{-\lambda t}\left(1+\lambda t+\frac{\lambda^2t^2}{2!}+\cdots+\frac{\lambda^{i-1}t^{i-1}}{(i-1)!}\right)\right],$$

where ϕ_i represents neutron flux and λ the time constant of a single isolated stage. Fast-neutron feedback appears to have little effect on the kinetic behavior. Delayed neutrons will have the same effect as in a reactor operating well away from the critical condition.

Use of a mobile fuel permits transport of the delayed-neutron emitters to an earlier amplifier stage where they can provide all the necessary excitation without an external neutron source. The time between neutron generations for such a system will be determined by the circulation rate, characteristic of the delayed-neutron lifetime. This, therefore, constitutes a critical system with unlimited delayed-neutron control. Variation of the rate of delayed-neutron recycle provides complete control of the system; reproduction factors in excess of two are practical to initiate operation.

Variable feedback and nonlinear terms may be introduced to give the Convergatron the principal characteristics of electronic amplifiers.*

* *Note added in proof.*—After completion of this work my attention was called to an unpublished memorandum by R. W. Samsel (AEC-KAPL-M-RWS-1), dated February 14, 1947, proposing in qualitative form the control of a large reactor by a series of linear amplifier stages.

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Charge Independence and Hyperon Production*

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IN the hyperon production processes

$$\pi^-+p\rightarrow\Lambda^0+\theta^0,\qquad(1)$$

$$\pi^-+p\rightarrow\Sigma^-+K^+,\qquad(2)$$

$$\pi^-+p\rightarrow\Sigma^0+\theta^0,\qquad(3)$$

$$\pi^++p\rightarrow\Sigma^++K^+,\qquad(4)$$

the hypothesis of charge independence in the baryon-meson interaction leads to certain relationships among

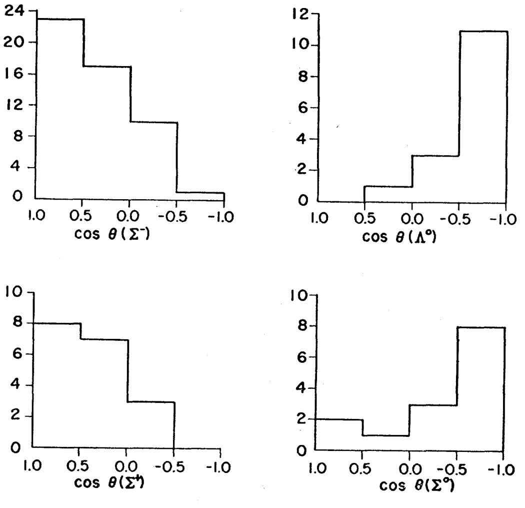

FIG. 1. Center-of-mass angular distributions of the production of hyperons by pions of 1.1-Bev kinetic energy striking free protons in propane. Σ^+ hyperons are produced by π^+ mesons, and Λ^0, Σ^0, and Σ^- hyperons by π^- mesons.