noted explorer of the Grand Cañon of the Colorado River. Under present arrangements a lecture is delivered at each annual meeting of the division by a distinguished investigator in some field of science upon a topic of his own selection. The roll of lecturers and the fields represented are as follows:

1929. William Morris Davis, Harvard University (Geology).
1930. Rodney H. True, University of Pennsylvania (Botany).
1932. Max Pinner, Desert Sanatorium of Southern Arizona (Medicine).
1933. Aldo Leopold, University of Wisconsin (Forestry).
1934. Otto Struve, University of Chicago (Astronomy).
1935. Edgar L. Hewett, University of New Mexico (Archeology).
1936. John C. Merriam, Carnegie Institution (Paleontology).
1937. A. E. Douglass, University of Arizona (Astronomy).
1938. E. R. Hedrick, University of California, Los Angeles (Mathematics).
1939. A. H. Compton, University of Chicago (Physics).
1940. D. T. MacDougal, Carnegie Institution (Botany).

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SPECIAL ARTICLES

A NEW TYPE OF VIRUS FROM EPIDEMIC INFLUENZA[1]

IN February and March of 1940, an epidemic of acute respiratory disease, simulating epidemic influenza, occurred at Irvington House, a convalescent home for children with rheumatic cardiac disease, located at Irvington on Hudson. Through the courtesy of Dr. Ann G. Kuttner, throat washings were received from 4 cases in the first 3 days of illness and, in addition, samples of serum were taken in the acute and convalescent stages. Neutralization tests done with these sera revealed no rise in antibody titer during convalescence against 1000 M.L.D. of the PR8 strain of the virus of epidemic influenza. Mice and ferrets were inoculated intranasally with 3 of the throat washings. Two of the ferrets failed to exhibit recognizable signs of infection and their sera, taken 8 and 51 days later, respectively, failed to neutralize the standard PR8 strain of virus. Attempts to isolate a virus directly in mice from any of the throat washings were unsuccessful through 5 serial passages at 4-day intervals or 10, 21 and 23 passages, respectively, at 7-day intervals.

The temperature of the ferret inoculated with throat washings from the third patient (Lee) fell to subnormal on the 5th and 6th days. The animal stopped eating, was abnormally quiet and had some respiratory distress. At autopsy on the 6th day the only gross finding was a mild, bluish discoloration of the left lower lobe of the lung. Passage to a normal ferret was made with a suspension of lung and turbinates and 13 serial transfers were made at 4- to 6-day intervals in this species of animal. After the 5th passage a double series was maintained. In 2 of the 20 ferrets, the highest temperature was above 105° F.; in 7, it was 104–5°; in 6, between 103.5° and 104°; in 3, no evidence of fever was obtained and in 2 the temperature was subnormal. In 13 of 18 autopsied ferrets mild pulmonary lesions, usually spotty, were noted and the majority presented abnormalities of the respiratory turbinate tissue. Serum taken from the sole convalescent ferret (B77–9th passage) on the 21st day failed to neutralize 1000 or 100 M.L.D. of the mouse passage PR8 strain of virus. Hence, by the criteria established in 1937[2] this outbreak of respiratory disease was not associated with the virus of epidemic influenza.

Groups of mice were inoculated intranasally with suspensions of lung, turbinate or both from ferrets of the 5th, 7th, 8th, 9th, 10th and 13th passages and multiple transfers were made with lung suspensions by the intranasal route at 4- to 6-day intervals. Using 40 per cent. suspensions, only small lesions were as a rule observed in mice of the first 5 passages. Thereafter, an increase in severity of the disease occurred so that by the 10th transfer infections were frequently fatal within the 5-day period. With continued passage the virulence increased so that at present virus of the two series which have been continued through 40 passages produces fatal infection within 10 days when used in a 1:1000 dilution, occasionally 1:10,000, of infected mouse lung.

Throughout its development the lesions produced by the virus in the lungs of mice have been of the uniform reddish blue type seen in infections with the virus of epidemic influenza. Nevertheless, when tested against rabbit or ferret serum prepared against numerous different strains of epidemic influenza virus, no neutralization of 200 M.L.D. or less of the Lee virus was effected. It was not neutralized by rabbit sera pre-

[1] This study was assisted by grants from the International Health Division of the Rockefeller Foundation and from the Lederle Laboratories.

[2] T. Francis, Jr., T. P. Magill, E. R. Rickard and M. D. Beck, *Am. Jour. Pub. Health*, 27: 1141, 1937.

pared against several strains of poorly defined agents, probably of mouse origin, or by serum against normal mouse virus obtained from Dr. F. L. Horsfall, Jr. (Table I). On the other hand, rabbit serum prepared against one passage strain of the Lee virus completely neutralized 3 substrains established in mice with material from 3 different ferret passages (8, 8A, 13A). It was then found that the convalescent serum of ferret B77, which had failed to neutralize the PR8 strain, completely neutralized the Lee strain. The virus transferred in mice and ferrets appeared therefore to be identical.

TABLE I

COMPARATIVE SEROLOGICAL TESTS WITH EPIDEMIC INFLUENZA VIRUS (PR8) AND NEW VIRUS (LEE)

Animal	No.	Immunized with virus strain	Neutralization of 100 M.L.D.	
			Influenza virus (PR8)	Lee virus
Ferret	A7	PR8	+	0
"	1199	PR8 (hyperimmune)	+	0
"	1301	Swine	0	0
"	B66	Normal	0	0
Rabbit	N3	PR8 (hyperimmune)	+	0
"	N41	PR8	+	0
"	N47	WS	±	0
"	317	WS	0	0
"	204	Mel	+	0
"	299	BH2	+	0
"	302	Tal	+	0
"	330	Bl5	+	0
"	240	Mo5	+	0
"	241	NY2	0	0
"	226	Phila	+	0
"	214	Smithb	+	0
"	259	TF	+	0
"	327	Henry	+	0
"	N54	Lee	0	+
FOLLOWING RECEIVED THROAT WASHINGS OF PATIENTS OR PASSAGES THEREFROM				
Ferret	B32	Duke no. 7	0	+
"	B45	Duke no. 2	0	+
"	B46	Duke no. 5	0	+
"	B52	Irv. no. 1	0	0
"	B53	Irv. no. 2	0	0
"	B77	Irv. no. 3 (Lee)	0	+

The sera of the Irvington House patients which had exhibited no rise in convalescent titer against the standard PR8 strain were tested against a 10 per cent. mouse lung suspension (100 M.L.D.) of the Lee virus. The titers of both acute and convalescent sera of patient, Lee, were approximately the same when measured against PR8. Against the Lee strain the acute titer was 0; the convalescent titer, 120. A similar result was obtained with sera of 2 others, while in one instance no difference was detected. Sera from 4 other patients who had been sick during the epidemic were fortunately available. All these also showed in convalescence a pronounced rise in antibodies to the Lee virus but not to PR8 (Table II). These results seem clearly to establish the causal association of Lee virus with the Irvington House epidemic and to demonstrate the lack of serological relationship of that virus to strains of virus isolated from other epidemics of influenza.

TABLE II

COMPARISON OF NEUTRALIZING ANTIBODIES AGAINST LEE VIRUS AND THE PR8 STRAIN OF EPIDEMIC INFLUENZA VIRUS IN SERUM FROM PATIENTS IN DIFFERENT EPIDEMICS

Epidemic	Patient	Titer of neutralizing antibodies against			
		Lee virus +		PR8 Influenza ‡ virus	
		Acute	Convalescent	Acute	Convalescent
Irvington House 1940	Lee	0	120	120	100*
	Such.	0	90	35	60*
	My.	0	0	30	30*
	Dem.	0	30	60	60*
	Tren.	0	15	0	0
	Wo.	0	120	80	80
	Cast.	0	120	280	280
	Gouv.	0	240	280	280
No. Carolina 1940	Mar.	0	60	17 (0)	17 (0)
	Sp.	0	15	8 (0)	8 (0)
	Ha.	0	120	120 (30)	120 (30)
	Led.	0	60	30 (0)	30 (0)
	Mit.	0	15	15 (0)	15 (0)
	Dav.	0	30	25 (0)	25 (0)
	Kir.	15	0	15 (0)	4 (0)
Feb., 1936 (Unidentified)	Vr.	0	240	0	0
	B. Bas.	15	240	50	50
1936–37 Influenza	Hum.	60	60	50	320
	Web.	30	50	0	35

+ Approximately 100 M.L.D. of Lee virus used.
‡ Approximately 100 M.L.D. of PR8 virus used. The sets of sera marked with asterisk or in parentheses were tested with 1000 M.L.D.
Endpoints estimated by the method of Reed and Muench.[3]

In January and February of 1940 an extensive epidemic of what appeared to be epidemic influenza extended throughout the southeastern portion of the United States. Through the kindness of Dr. D. T. Smith and members of the medical staff of Duke University Hospital, patients were made available for study. Since these investigations were undertaken toward the end of the epidemic, throat washings or sputum and serum taken during the acute and convalescent stages of illness were obtained from but 7 patients. Four of the throat washings were given intranasally to ferrets. In two instances serial passages through 4 ferrets were made. While some of the ferrets exhibited signs suggestive of infection with influenza virus, attempts to maintain the infection or to isolate a virus in mice were unsuccessful. The fourth passage ferrets (B45, B46) were bled on the 12th day; another (B32) on the 28th day. Their sera failed to neutralize the PR8 strain. Furthermore, when neutralization tests with the acute and convalescent sera of the patients were performed, using 100 and 1000 M.L.D. of the standard PR8 strain of epidemic influenza virus, no diagnostic rise in antibodies was detected. In this instance, again, the customary procedures had indicated that the virus of epidemic influenza was not involved.

[3] L. J. Reed and H. Muench, *Am. Jour. Hyg.*, 27: 493, 1938.

In view of the studies of the Irvington outbreak, the various sera were retested against 100 M.L.D. of the Lee virus. In 6 of the 7 patients a definite rise in titer of the convalescent serum was seen (Table II). Furthermore, serum of 3 ferrets receiving throat washings from these patients neutralized the Lee virus, although they had failed to neutralize the PR8 strain. In addition, serum from 6 ferrets inoculated by Dr. Horsfall with throat washings of patients from the North Carolina epidemic were tested. Four of them neutralized the Lee virus, all failed to neutralize 100 M.L.D. of the PR8 strain. The serum of 3 patients which had been found by Dr. Horsfall to show no increased convalescent titer against the PR8 strain, when tested against the Lee virus, exhibited marked rises in neutralizing antibodies. It is evident, therefore, that the Lee virus was the cause of the earlier general outbreak in North Carolina and adjoining areas.

In the early months of 1936 a widespread epidemic of acute, respiratory disease, indistinguishable from epidemic influenza, was studied. Its etiology was not established nor was any evidence obtained relating it to known strains of the virus of epidemic influenza.[4] Sera from 2 typical patients which had been kept in storage since that time were now tested against 100 M.L.D. of influenza (PR8) and Lee viruses. Pronounced rises of titer against Lee virus occurred but not against PR8 (Table II). It appears, in consequence, that this epidemic 4 years earlier was also due to virus of the Lee type.

Reference was then made to acute and convalescent sera of 2 individuals from whom epidemic influenza virus was isolated during the epidemic of the winter of 1936–37 (Table II). Titered against the PR8 strain, rises from 0 to 35 and 50 to 320 were noted; against 100 M.L.D. of the Lee strain the acute and convalescent titers of both were approximately 60. Hence, infection of human subjects with virus of the PR8 type does not result in a rise of antibodies to the Lee virus and the difference in etiology of the epidemics is further demonstrated.

Again through the kindness of Dr. Horsfall, serum of ferrets inoculated with throat washings of patients observed in the epidemic of influenza current in the West Indies this summer were tested. Certain of these sera also neutralized the Lee virus but not the PR8.

The immunological evidence indicates clearly that the newly isolated virus is the cause of the epidemics of acute respiratory disease in Irvington and North Carolina in 1940 and of the extensive epidemic early in 1936. These epidemics have presented no outstanding clinical features to differentiate them from the outbreaks which have yielded the virus of epidemic influenza, typified by the original WS and PR8 strains. The serological studies reveal, however, that they are etiologically distinct. In fact, the lack of cross reactions between serum against known strains of influenza virus and the present virus suggests that the latter is entirely unrelated to the virus of epidemic influenza previously isolated. Complement fixation tests which ordinarily detect the common antigen of different strains of epidemic influenza virus have not yielded up to the present any helpful information. Hyperimmune PR8 rabbit and ferret sera have not neutralized even small amounts of Lee virus. Furthermore, mice vaccinated with 2 intraperitoneal injections of 5 per cent. Lee virus have died of infection with 100 M.L.D. of PR8 but staunchly resist the same amount or more of the Lee virus. The differences are clearly greater than those detected in previous studies of strains of epidemic influenza virus.[5, 6, 7] The behavior of the virus in animals and the gross pathological features are, however, quite the same as those of mild strains of known influenza virus.

The usual experience has been that human subjects infected with one strain of influenza virus produce antibodies readily detected by tests with any of the ordinary strains obtained from man, or even with strains of swine influenza virus. The absence of antibodies to the Lee virus in the serum of patients at the time of their infection and the production of specific antibodies to that virus in convalescence are independent of antibodies to the PR8 strain which remain constant during the course of this disease. It is evident, therefore, that for the purposes of differential diagnosis, the Lee virus represents a serologically distinct entity. Nevertheless, the epidemic disease associated with virus of the Lee type appears on the basis of present knowledge to be as typical of epidemic influenza as that prevalent in outbreaks from which strains of the previously recognized virus were obtained. The epidemics of 1936–37 and 1938–39 have been shown to be caused by influenza virus of the usual variety while those of early 1936 and 1940 are of the Lee type. The two infections apparently possess independent cycles, but until further differential studies are made they should both be considered epidemic influenza caused by viruses of different serological types. The isolation of the new type of virus and the accompanying serological studies have established the etiology of epidemics of acute respiratory disease simulating influenza which had previously not been identified. Following the classification recently suggested[8] in which

[4] T. Francis, Jr., *Am. Jour. Pub. Health*, 27: 211, 1937.

[5] T. P. Magill and T. Francis, Jr., *Brit. Jour. Exp. Path.*, 19: 273, 1938.

[6] T. Francis, Jr., and T. P. Magill, *Ibid.*, p. 284.

[7] W. Smith and C. H. Andrewes, *Ibid.*, p. 293.

[8] F. L. Horsfall, Jr., E. H. Lennette, E. R. Rickard, C. H. Andrewes, W. Smith and C. H. Stuart-Harris, *Lancet*, 2: ——, October 5, 1940.

the established form of epidemic influenza is called Influenza A, outbreaks caused by virus of the Lee type are to be designated Influenza B.

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THE VIBRATION OF CIRCULAR PLATES

THE equation for the nodal lines of a circular plate was worked out by Kirchhoff in 1850, having the form

$$w = J_n(kr)\cos(n\theta - \alpha) \quad (1)$$

The first factor of this equation will give circles of different radii, while the second represents diameters. For nearly one hundred years this equation has been considered to be the most general possible solution so that the conclusion seemed inescapable that only circles and diameters could appear upon a circular plate. When plates are actually vibrated, however, many symmetrical patterns appear upon them which are certainly not circles. These variations from the theory were thought to be due to asymmetries in the plates, such as varying thickness, different tensions and so forth. If the assumption is made that a circular plate can give out two or more notes at the same time, then the equation of Kirchhoff may be extended in the form

$$w = AJ_n(kr)\cos n(\theta - \alpha_n) + BJ_m(k'r)\cos m(\theta - \alpha_m) \quad (2)$$

When this equation is zero (the condition for nodal lines), the resulting figures are much more complicated than mere circles and diameters. It will be proved that they correspond to the figures produced by experiment.

In Fig. 1 are shown tracings from photographs of circular vibrating plates. The originals will be found in another article by one of the writers.[1] Below them in Fig. 2 are the mathematical curves resulting from

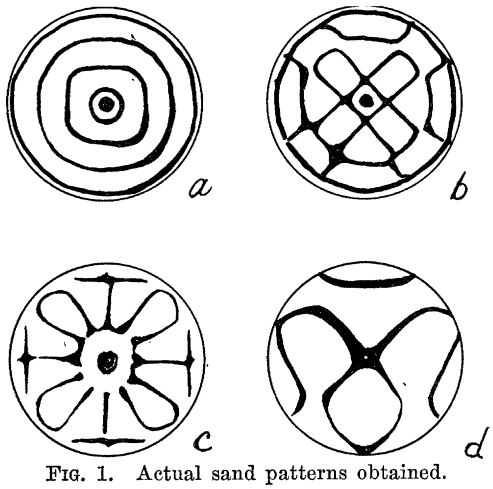

FIG. 1. Actual sand patterns obtained.

[1] Robert C. Colwell, *Jour. Franklin Inst.*, 213: 373–380, 1932.

substitution in Equation 2 of the proper numerical values. The exact equations for these are in order:

$$\left.\begin{aligned} 3J_0\left(\frac{12.53r}{a}\right) + J_4\left(\frac{11.95r}{a}\right)\cos 4\theta = 0 \quad (2a)\\ J_0\left(\frac{12.53r}{a}\right) + 2J_4\left(\frac{11.95r}{a}\right)\cos 4\theta = 0 \quad (2b)\\ J_2\left(\frac{5.937r}{a}\right)\sin 2\theta - 5J_6\left(\frac{11.00r}{a}\right)\sin(6\theta) = 0 \quad (2c)\\ J_2\left(\frac{5.937r}{a}\right)\cos 2\theta + J_3\left(\frac{3.497r}{a}\right)\cos 3\theta = 0 \quad (2d)\end{aligned}\right\} \quad (3)$$

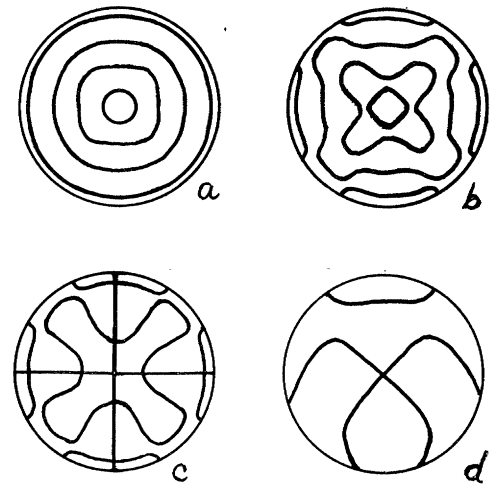

FIG. 2. Theoretical curves calculated.

The values of A and B are found by trial. After considerable experience one becomes more or less expert in picking out the number of circles and diameters in the Bessel and cosine functions which must be combined to produce any given figure. For instance, Fig. 2(*c*) is obtained as shown in Equation 3, for $A = 1$, $B = -5$. If these ratios are changed, another equation appears whose plot resembles 2(*c*) but differs from it in some important details. In Fig. 3 are shown two curves obtained from the equations

$$\left.\begin{aligned} J_2\left(\frac{5.937r}{a}\right)\sin 2\theta - 10J_6\left(\frac{11.00r}{a}\right)\sin 6\theta = 0\\ J_2\left(\frac{5.937r}{a}\right)\sin 2\theta - 10J_6\left(\frac{11.00r}{a}\right)\sin(6\theta - 5°) = 0\end{aligned}\right\} \quad (4)$$

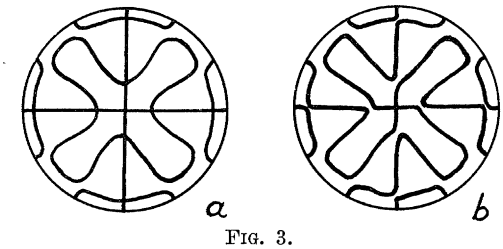

FIG. 3.

Simply varying the angle by 5° in Equation 4 causes the lines to split up. Both curves resemble that of Fig. 2(*c*) because similar functions are combined, although in different proportions.