

$$k = a \left(\frac{\mu^2}{\rho \sigma d} \right), \dots \dots \dots (1)$$

where k is permeability, darcies; μ is viscosity, poises; ρ is density, gm./cal.; σ is surface tension of liquid, dynes/cm.; d is average diameter of pores, cm. (Strictly, σ should be the interfacial tension between liquid and the material of the sample.) As d was constant for one sample, a plot of k versus $\mu^2/\rho\sigma$ was made, and it was found that a unique curve was obtained for all the liquids used. The equation of this curve was

$$\log k = 0.1 \log \left(\frac{\mu^2}{\rho \sigma} \right) + A \dots \dots \dots (2)$$

or, in general,

$$\log k = A + B \log \left(\frac{\mu^2}{\rho \sigma d} \right) \dots \dots \dots (3)$$

Thus, the permeability will have two terms: (i) A , the permeability due to ordinary hydrodynamic phenomena observed in large-scale systems and characterized by being a constant independent of the nature of the liquid flowing, (ii) B a second term involving the viscosity, density and surface energy of the liquid. It is seen from (3) that for any liquid as d increases this effect of increasing the permeability decreases. Thus in very narrow channels water will probably flow in the layers adhering to the surface; that is, where A , the hydrodynamic factor, is negligibly small, flow can still occur in the bound surface layer. Air, on the other hand, can only flow by virtue of the A term in the permeability equation as it has a much less effective hold on the surface; B for air is probably vanishingly small.

To summarize: flow appears to follow two mechanisms: (i) ordinary hydrodynamic flow in surface-free systems; (ii) sub-viscous regime flow where the molecules adsorbed at the surface exchange places under distinctly different laws from those observed in non-boundary conditions. In very narrow channels the second form of flow becomes a significant portion of the total flow.

A. H. NISSAN.

University,
Edgbaston,
Birmingham, 15,
Sept. 26.

¹ Reekie, J., and Aird, J., *Nature*, **156**, 367-368 (1945).

² Nissan, A. H., *Nature*, **148**, 503 (1941).

³ Grunberg, L., and Nissan, A. H., *J. Inst. Petrol.*, **29**, 193 (1943).

Flow of Fluids through Porous Plugs and the Measurement of Specific Surface

In a communication published recently on "Flow of Water through Very Narrow Channels", Reekie and Aird¹ give results obtained from measurements of the flow of both water and air through plugs of very fine powders having estimated channel widths of 0.07-0.2 micron. Although anomalous flow of water in such narrow channels was suspected, it should be pointed out that it is the flow of air which is, in fact, anomalous under such conditions. The streamline flow of a gas through a narrow capillary tube departs slightly from the normal Meyer equation due to 'slip' of the gas at the wall. While for narrow glass capillary tubes, for example, 0.05 cm. in diameter, the correction for 'slip' amounts only to about 0.1 per cent, the correction assumes much bigger proportions when the diameter of the tube is comparable with the 'mean free path' (λ) of the molecules in the gas. In air at 2 atmospheres pressure, the value of λ is about 0.05 micron² and is thus similar in magnitude to the channel widths quoted by Reekie and Aird. Under such conditions the flow of air through a capillary does not obey the ordinary laws of viscous flow. Since the effect of 'slip' is to decrease the apparent viscosity of air, this factor may account for the very high values of viscosity of water deduced by Reekie and Aird from their experiments.

Using compressed powder plugs having channel widths of the order of 1 micron and correcting for 'slip' at the walls, I have obtained concordant results for the flow of both air and liquids. These experiments were carried out in connexion with a theoretical study of the 'air permeability' method for determining the specific surface of a powder². The original equation relating surface area to permeability for a compressed bed of particles was derived by Kozeny³ for liquids. Lea and Nurse⁴ and others have applied this equation to air permeability and, in the case of fine powders, found discrepancies between values of surface area determined by air and by liquids; specific surface determined by liquid permeability is normally higher

than that given by the air method. Theories put forward to account for these discrepancies have usually postulated the existence of immobile layers of liquid on the channel walls which diminish the effective diameter of the channels. The probable explanation is, however, not that the 'liquid value' is too high, but that the 'air value' is too low when calculated from the normal Kozeny equation. Typical results are given herewith for three common mineral powders to show that if the Kozeny equation is corrected for 'slip', the value of specific surface deduced from air flow measurements agrees with values obtained by the liquid method.

The normal equation for the U-tube form of apparatus⁵ is

$$S^2 = \frac{2A \epsilon^2 g d T}{k(1-\epsilon)^2 \eta \rho^2 a L \log_2 (h_2/h_1)}$$

When modified to correct for 'slip' at the walls, it becomes

$$\frac{k \eta a L \log_2 h_2/h_1}{2A \epsilon g d T} = \frac{1}{S^2} \left(\frac{\epsilon}{1-\epsilon} \right)^2 + \frac{1}{S} \left(\frac{\epsilon \zeta}{2(1-\epsilon)\rho} \right)$$

where $\zeta = 3.48 \lambda$.

The validity of this correction term has been investigated by making tests over a wide range of pressure on a specially modified Lea-Nurse form of apparatus so as to provide a range of λ values in the plug of powder. I hope to publish a detailed description of these experiments elsewhere.

P. J. RIGDEN.

Road Research Laboratory,
Department of Scientific and Industrial Research,
Harmondsworth,
Nov. 9.

¹ Reekie, J., and Aird, J., *Nature*, **156**, 367 (1945).

² Kaye and Laby, "Phys. and Chem. Constants" (2nd ed.), 33.

³ Rigden, P. J., *J. Soc. Chem. Ind.*, **62**, 1 (1943).

⁴ Kozeny, *Ber. Wien. Akad.*, **136 a**, 271 (1927).

⁵ Lea, F. M., and Nurse, R. W., *J. Soc. Chem. Ind.*, **58**, 277 (1939).

The Beta-Activity of the Neutron

To establish the possible radioactivity of the neutron, K. C. Wang has suggested a spectroscopic test for hydrogen in a mass of liquid heavy hydrogen or preferably in liquid helium after irradiation by slow neutrons. Some evidence for the beta-activity of the neutron is found in the experiments on the scattering of neutrons in deuterium, carried out by J. F. Streib and myself². The details of the method and a photographic record of the recoil pulses have been given³.

The cathode ray oscillograph used for the visual check of the recoils revealed that about one in twenty of the pulses corresponded to neutron energies much in excess of the highest energy group of neutrons released in the Be-D nuclear reaction⁴ by the 600 kilo-volt peak accelerating voltage used in the experiments. The disappearance of these pulses with the stoppage of neutron production ruled out the possibility that they were of cosmic ray origin. It now looks probable that the high energy recoil pulses are to be associated with the radio-activity of the neutron. The decay of some of the neutrons in the ionization chamber may have been favoured by the irregular scattering in the one-foot thick concrete walls of the small-size enclosure housing the detection apparatus. The cloud chamber studies of the beta-activity of Cl(38) by Crane and Halpern⁵ show that momentum need not be conserved in a system consisting only of the emitted beta-particle and the nucleus.

C. K. SUNDARACHAR.

University of Mysore,
Central College,
Bangalore,
Sept. 10.

¹ Wang, K. C., *Nature*, **155**, 574 (1945).

² Sundarachar, C. K., and Streib, J. F., *Nature*, **149**, 51 (1942).

³ Sundarachar, C. K., and Streib, J. F., *J. Mys. Univ.*, **3**, 55 (1942).

⁴ Bonner and Brubaker, *Phys. Rev.*, **50**, 308 (1936).

⁵ Crane, H. R., and Halpern, J., *Phys. Rev.*, **56**, 232 (1939).

Determination of Small Quantities of Phosphorus in Steel

Berenblum and Chain's modification¹ of Fiske and Subbarow's method for the determination of phosphorus has been adopted in this Laboratory for the determination of small quantities of phosphorus in steels.

As a unit, working in the field, under active service conditions, the method has been found to give good results and to possess at least two advantages: (1) it is rapid (2-3 hours), (2) it requires but very small samples of the substance under test (0.05-0.20 gm.). Frequently, inadequate quantities of samples have been submitted for analysis, so that not enough has been available for the determination of phosphorus by the ordinary method of precipitation as ammonium phosphomolybdate.

Method: The method is that described by Berenblum and Chain, with the following exceptions. (1) The final steel solutions were, perforce, acid and not neutral, as is recommended. (2) Iso-amyl alcohol was used instead of iso-butyl alcohol, owing to the non-availability of the latter. (3) The final blue iso-amyl alcoholic solution of reduced phosphomolybdic acid was washed three times, each with 5 ml. portions of the diluted stannous chloride reagent in N sulphuric acid. This procedure was adopted in order to remove certain unidentified substances which interfere, imparting to the final blue solution a slight violet tinge. These substances are removed by the washing process. (4) Comparison of the final blue solution was made by means of a Dubose colorimeter.

The following, then, is a brief résumé of the method adopted: To 5 ml. of solution under test (containing of the order of 1 µgm. phosphorus

Powder	Specific surface (sq. metres/gm.) obtained from		Liquid-permeability	Mean channel width (micron)
	Air-permeability			
	calc. by normal equation	calc. by modified equation		
Fine silica dust	1.15	1.51	Acetone 1.48 } 1.49	0.6
	1.08	1.49		
Portland cement	0.552	0.878	Acetone 0.840 } 0.837	1.0
"Air-blown" slate dust	2.22	3.00	Acetone 3.01	0.7