



Ain Shams University
Faculty of Education

***Magnetohydrodynamics Stability Problems and
Their Applications in Fluid Mechanics and
Plasma Physics***

THESIS

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مسائل استقرار الإتزان الهيدرومغناطيسي و تطبيقاتها في ميكانيكا الموائع وفيزياء البلازما

رسالة مقدمة

كجزء متمم للحصول على درجة دكتوراه الفلسفة في
إعداد المعلم في العلوم (فيزياء نظرية)

مقدمه إلى

قسم الفيزياء - كلية التربية - جامعة عين شمس
من

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ماجستير في إعداد المعلم في العلوم (فيزياء)
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CHAPTER 1.

INTRODUCTION

1.1 Some Properties of Fluid

1.1.1 Pressure

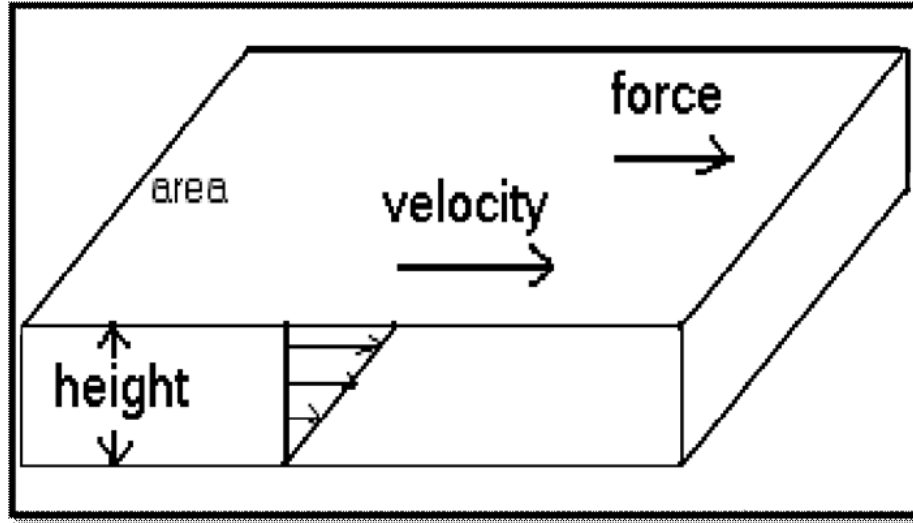
The pressure in a static fluid is defined as the normal compressive force per unit area acting on a surface immersed in the fluid. The pressure at a point is isotropic in a fluid at rest. This is the pressure used in thermodynamics (gas law) and is a thermodynamic property. If the pressure varies from place to place in the fluid a net pressure force would exist on any fixed volume of fluid and must be balanced by a body force such as gravity, or else the fluid will move, the pressure force generating an accelerating in the fluid; [57].

1.1.2 Viscosity

All fluids have viscosity in varying degrees which causes friction. If the friction is negligible, we say the flow is ideal. The coefficient of viscosity of fluid may be defined as the tangential force required per unit area (shearing stress) to a unit velocity gradient. The dimensions of the coefficient of viscosity μ can be found as follows:

$$\mu = \frac{\text{shearing stress}}{\text{velocity gradient}} = \frac{\text{force/area}}{\text{velocity/height}} = ML^{-1}t^{-1} \quad (1..1)$$

where M , L and t refers to units of mass, length and time respectively.



Figure(1 – 1)

Figure (1.1) illustrates the steady shear flow of a fluid between a fixed plate and a parallel plate, illustrating the concept of viscosity.

1.1.3 Kinematic viscosity

Kinematic viscosity is the ratio between the coefficient of viscosity μ and the mass density ρ (the mass of unit volume of the fluid, which has the dimensions ML^{-3}).

The dimensions of the kinematic viscosity ν can be found as:

$$\nu = \frac{\mu}{\rho} = \frac{ML^{-1}t^{-1}}{ML^{-3}} = L^2t^{-1} \quad (1.2)$$

1.1.4 Thermal conductivity

The coefficient of thermal conductivity can be defined from Fourier's law of heat conduction, which supposed that two parallel layers of fluid at a distance d apart, are kept at different temperature T_1 and T_2 . Fourier noticed that a flow of heat is set up

through the layer such that the quantity of heat Q_T transferred through unit area in a unit time is directly proportional to the difference of temperature between the layers and inversely proportional to the distance d , thus he found:

$$Q_T = \alpha \frac{T_1 - T_2}{d} \quad (1.3)$$

where (α) is the constant of proportionality and is known as the coefficient of thermal conductivity. If the distance (d) between two layers of fluid is infinitesimal the above law can be written in differential form as:

$$Q_T = -\alpha \frac{dT}{dy} \quad (1.4)$$

which is the Fourier's law of heat conduction, where the negative sign has been taken because the heat flows in the direction of decreasing temperature.

1.1.5 Permeability

Permeability is simply defined as the conductance of the porous medium via the Darcy's law as follows:

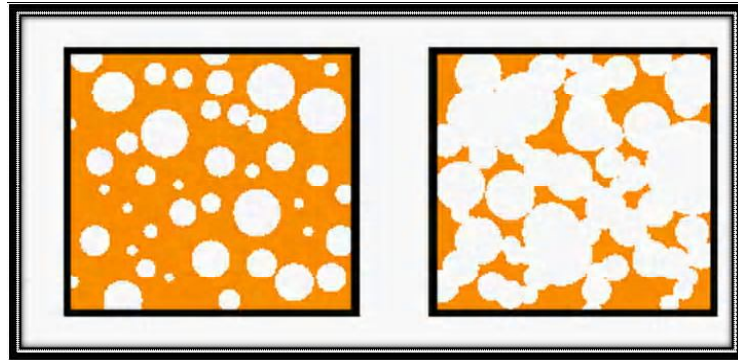
$$\frac{R}{A} = \left(\frac{K}{\mu}\right) \frac{\Delta P}{L} \quad (1.5)$$

Equation (1.5) is the physical law, relating the volumetric flow rate R through a porous medium having a normal area A under the pressure gradient $(\frac{\Delta P}{L})$, μ is the viscosity of the fluid, and K is the permeability of the porous medium. In other words, K is a measure of the resistance to fluid flow, and generally depends upon the pore size distribution, length, entrance, and exists of the pores, etc.

The permeability of a porous medium is expressed in terms of (darcy). A porous material is said to have a permeability of one darcy if a pressure difference of $1\text{gm}/\text{cm}^3$ of a fluid having viscosity of $1\text{gm}/\text{cm}$ through a cube (of porous matrix) having sides 1cm in length; [57].

1.1.6 Proposity

Proposity of the porous medium can be defined as the fraction of total volume, i.e., the total void volume divided by the total volume occupied by the solid matrix and void volumes. Each is connected to more than one other pore (inter-connected), connected only to one other pore (deal end), or not connected to any other pore (isolated) [figure (1-2)].



a- isolated porous medium

b- inter-connected porous medium

Figure(1 – 2)

The volume fraction of the interconnected pores is called the effective, for rigid matrices, the porosity doesn't show changes in the presence of pressure gradient.

The non-uniformity near the boundaries (confining solid or free surfaces) can play a significant role in the transfer rates at the boundaries and should be treated

with meaningful local distributions.

The measurement of porosity can be achieved by a variety of methods, for example, direct method applied to analysis of bread, optical method have been applied to porcelain, density method, gas expansion method and other methods (for more details see Schridegger [79]).

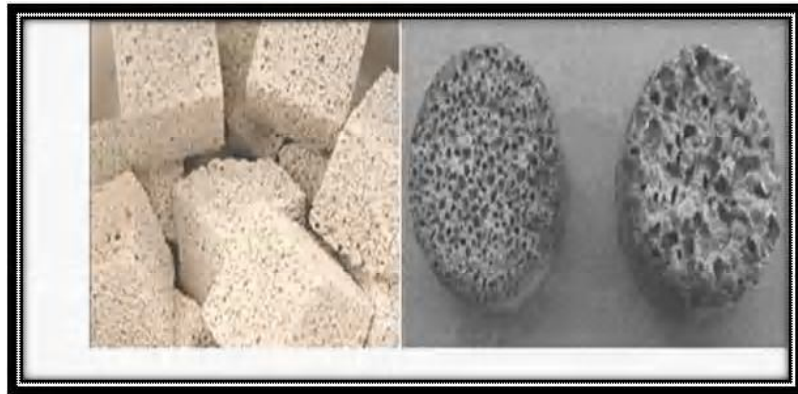
1.1.7 Flow Through a porous medium

A porous medium is literally a solid which contains a number of small holes distributed throughout the solid. Effective holes mean those holes through which the fluid can actually pass. Ineffective holes mean those holes through which the fluid cannot pass. These holes may either be so fine that fluid cannot move through them due to surface tension, or the holes may not be interconnected (isolated). If the holes are not interconnected (isolated) then the fluid cannot pass through them and thus these become ineffective. Porous media are very much prevalent in nature and, therefore the study of flow through porous medium is important role in agricultural and extracting pure petrol from crude oil.

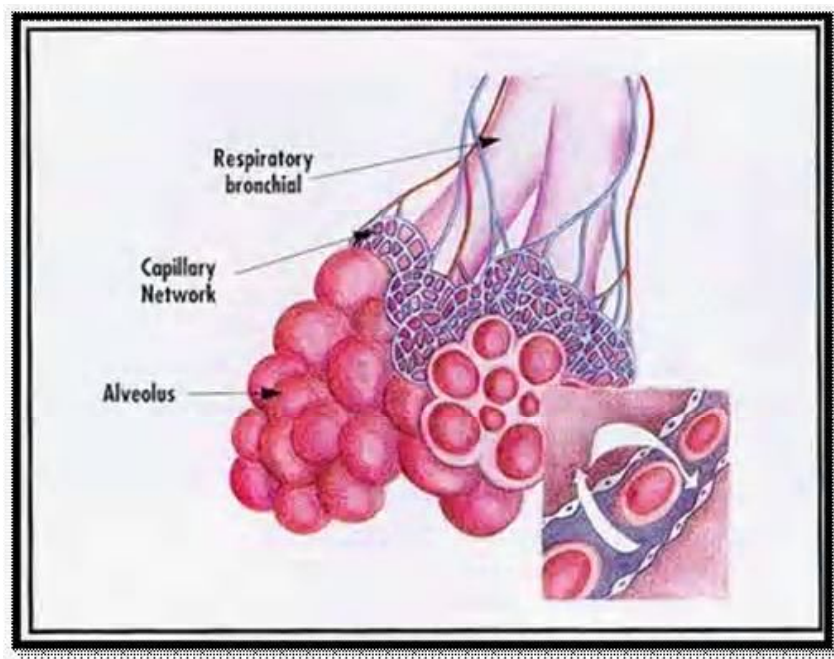
The study of the flow through porous medium is also important in many other branches of engineering and science, for example, ground water hydrology, reservoir engineering, soil science, soil mechanics and chemical engineering. Movement of underground water and oils are some important examples of flow through porous medium. Another examples of flow through porous medium is the seepage under a dam which is very important; [106].

There are examples of natural porous media such as beach sand, wood, filter

paper, loaf of bread, cotton, foamed plastics, sponges, gravel, sandstone, limestone, wicks, bricks and plaster wall [see figure (1-3)]. Rocks from underground for motion that contain natural gas, oil, or water are first classified as to their chemical composition, sandstone, limestone, chert, or serpentine. Roughly 40 percent of the oil reserve of the world are contained in sandstone formations. Sandstone consists of grains of quartz, usually cemented together with argillaceous materials. Roughly 60 percent of the oil reserves of the world are contained in limestone reservoirs. As a good biological examples on the porous medium, the human lungs [figure (1-4)] [www.pathology.vcu.edu], the gall bladder and bile duct with stones. Some tumors may be thought of as porous mass of cells interpenetrated by blood vessels. The walls of these vessels are permeable to plasma and some solutes. Hence fluid from the vessels continually leaks into the tumor. One method of chemotherapy involves the injection into the blood of specific chemicals that travel throughout the vascular system, including the vasculature of the tumor. When these chemical leak into the tissue region of the tumor, they act on the proliferating cells and kill them.



Figure(1 – 3)



Figure(1 – 4)

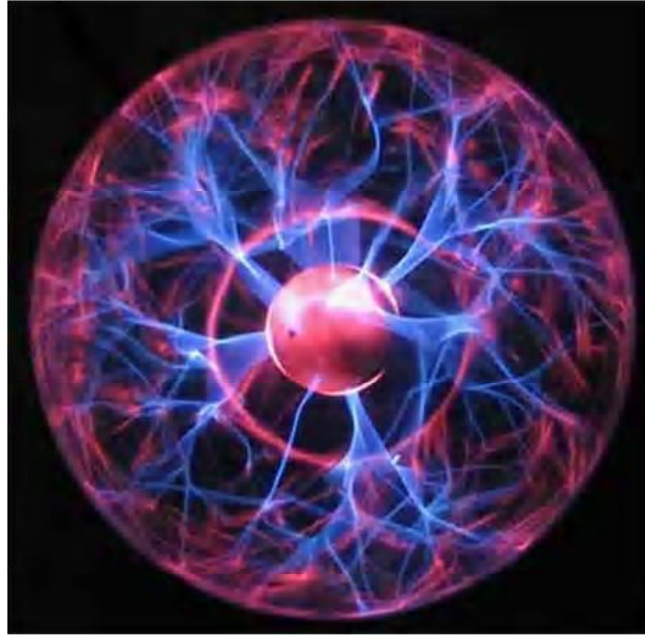
Porous media can be defined as solid bodies that contain void spaces (so called pores). These pores may be penetrated by a variety of fluids, so the solid phase is usually the solid matrix. Thus, in general, a porous medium consists of a portion of space occupied by heterogeneous or multiphase matter. The solid phase should be distributed through the porous medium in such away that it is presented inside any representative elementary volume; [132].

The permeability of a porous medium is a statistical average of the fluid conductivity of the flow channels in the medium. The average conductivity takes into account the variations in size, shape, direction and interconnections of all the flow channels. In a homogenous porous medium, the permeability at each point coincides with the average permeability; [134].

1.2 Plasma Physics

1.2.1 Experimental and theoretical approach to plasma physics

Plasma Physics started along two parallel lines. One of them was the hundred-year-old investigations into what was called "electrical discharges in gasses " [Figure(1-5)]. To a high degree, this approach was experimental and phenomenological, and only very slowly did it reach some degree of theoretical sophistication.



Figure(1 – 5): Picture of an active plasms taken from the top

Most theoretical physicists looked down on this field which was complicated and awkward. The plasma exhibited striations, double layers, and an assortment of oscillations and instabilities. The electron temperature was often found to be one or two orders of magnitude larger than the gas temperature, with the ion temperature intermediate. In short, it was a field which was not well suited for mathematically elegant theories.

The other approach came from the highly developed kinetic theory of ordinary gasses. It was thought that, with a limited amount of work, this field could be extended to include ionized gasses. The theories were mathematically elegant and claimed to derive all of the properties of a plasma from first principles. In reality, this was not true. because of the complexity of the problem, a number of approximations were necessary which were not always appropriate. The theories had very little contact with

experimental plasma physics; all awkward and complicated phenomena which had been observed in the study of discharges in gasses were simply neglected.

In cosmic plasma physics, the experimental approach was initiated by Birkeland, who was the first one to try to connect laboratory plasma physics and cosmic plasma physics. (Neither term was used at that time!) Birkeland observed aurorae and magnetic storms in nature and tried to understand them through his famous terrella experiments; [58]. He immersed his terrella in plasma and found that under certain conditions luminous rings were produced around the poles [Figure(1-6)]. Birkeland identified these rings were the auroral zones. As we know today, this is essentially correct. Further, he constructed a model of the polar magnetic storms, assuming that the auroral electrojet was closed through vertical currents(along the magnetic field lines). This was a natural assumption because his experiment was a study of electric current in ‘vacuum’. This idea was also correct as a first approximation (the current system is more complicated than he thought). Hence, although Birkeland could not have known very much about the detailed structure of the magnetosphere, research today essentially follows Birkeland’s lines, especially in the respect that the contact between laboratory experiments and astrophysics is important; [5, 40]. Unfortunately, the progress along these lines was disrupted. Theories about plasma, at that time called ionized gases, were developed without any contact with laboratory plasma work. In spite this -or perhaps because of this- belief in the theories was so strong that they were applied directly to space. One of the results was the Chapman - Ferraro theory which became