



**-STERILIZATION BY  
ATMOSPHERIC  
PRESSURE PLASMA  
-GLOW DISCHARGES  
-MHD SIMULATIONS**

**NECDET ASLAN  
Yeditepe University, Istanbul**



*Yeditepe University,*

*Istanbul TURKEY*

# ***Problem Definition***

**Sterilization of Micro Organisms (on surfaces  
and in water) at Low Temperatures by using  
Atmospheric Pressure, High Voltage AC  
and DC Power Supplies  
(*relatively new in area*)**

**&**

**Towards Developing 3D Numerical  
VISUAL-PARALLEL MHD CODE with  
Radiation, Mass and Heat transfer**

**EXPERIMENT & THEORY  
TOGETHER**



# *Methods*

**Sterilization** : elimination of all transmissible agents (such as bacteria, spors and viruses) from a surface, a piece of equipment, food or biological culture medium (e.g. water).

## **1. Physical:**

(i) Heat, presence or absence of moisture. (ii) Radiation

## **2. Chemical:**

(i) chemical solution (ii) chemical gases

## **3. Mechanical:** Filtration

### **Methods:**

*Steam Sterilization*

*Dry heat sterilization*

*Filtration*

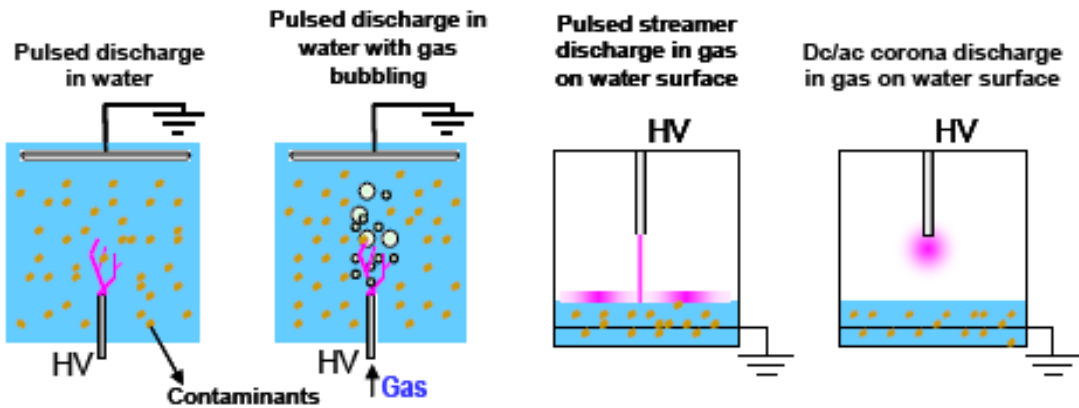
*Gas sterilization* (Explosive hazard , Toxic , not appropriate for solutions )

*Irradiation* : (Highly specialized equipment required

Effect of irradiation on products and their containers)



## Discharge in water/above water surface



Plasma formation

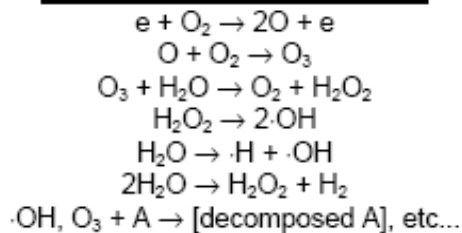
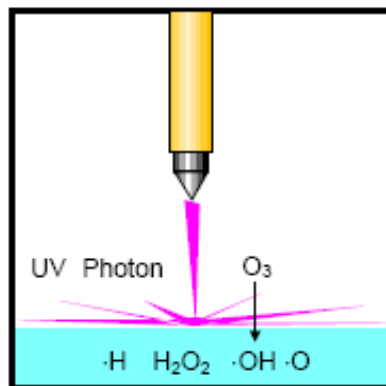
hard

easy

close to the target

Radicals / Plasma region

far from the target





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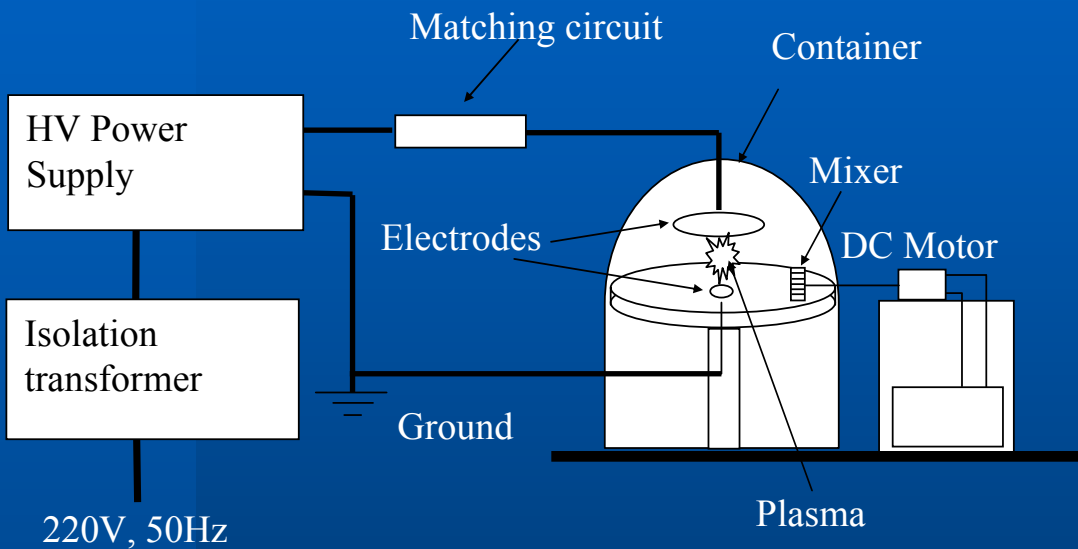
## ***EFFICIENT METHOD***

# Atmospheric Pinched Plasma Discharge





# Circuit and System Schematics





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## Algae Elimination



t=0

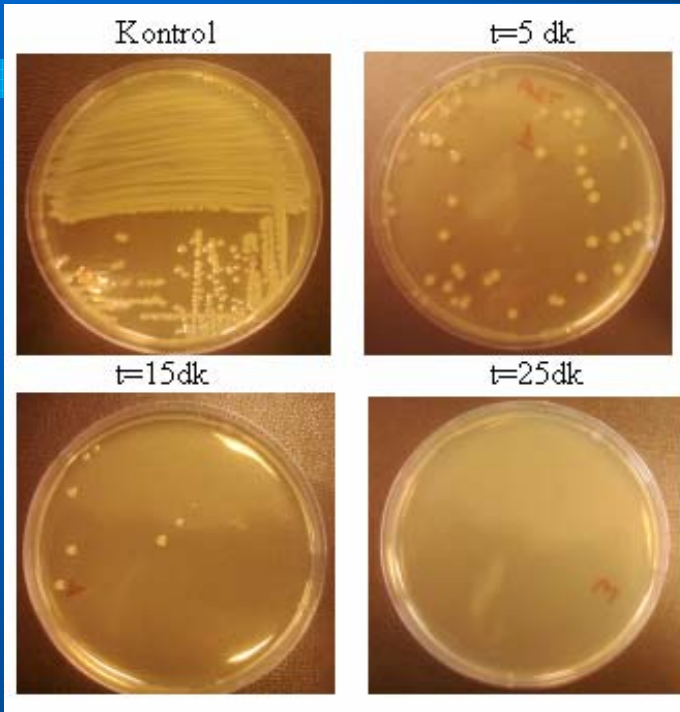
t=5min

t=15 min

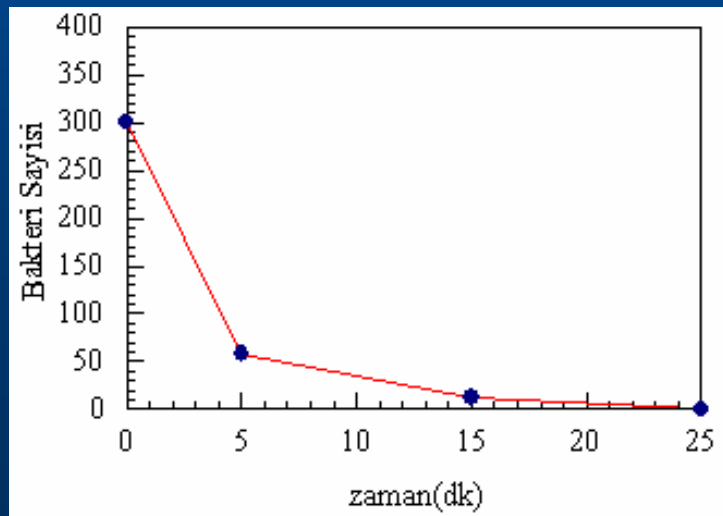
$$T_{\max} = 30^{\circ}$$



# Bacteria Sterilization



$$T_{\max} = 30^{\circ}$$

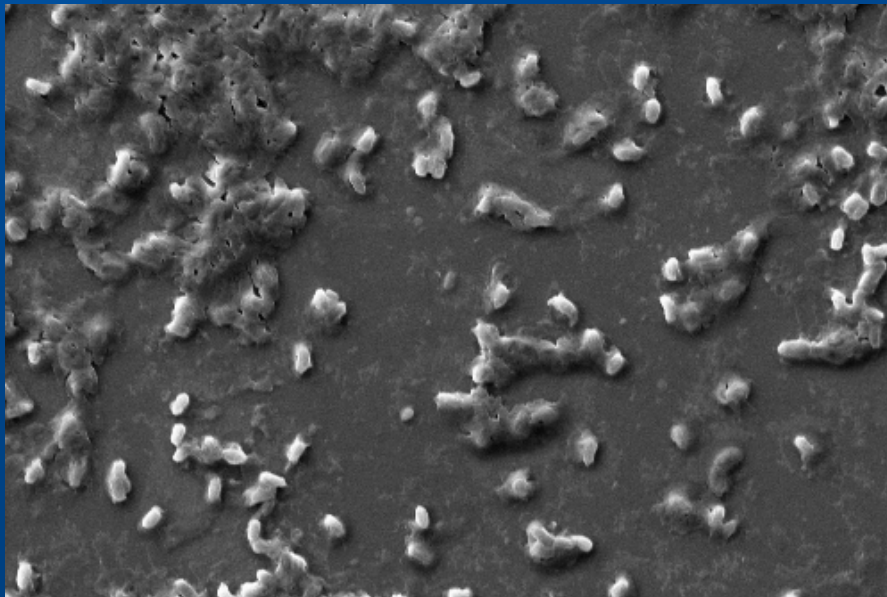
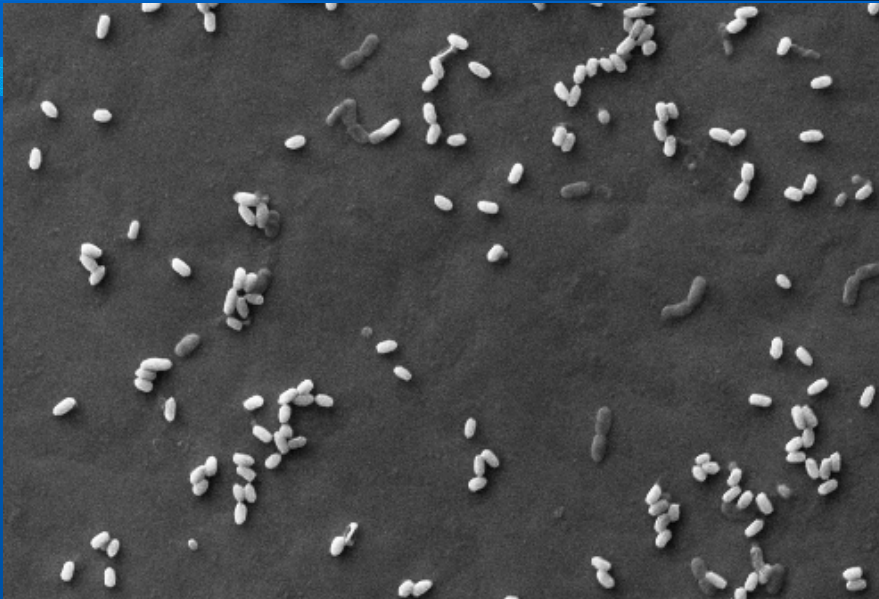




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## Bacteria on Surfaces

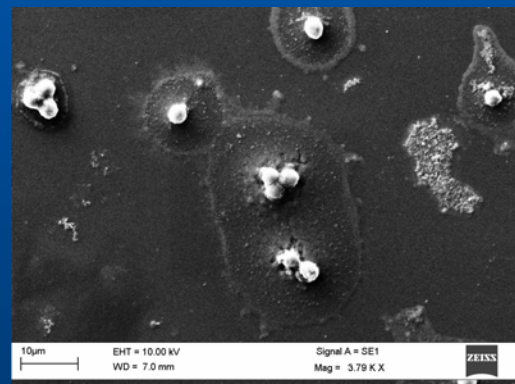
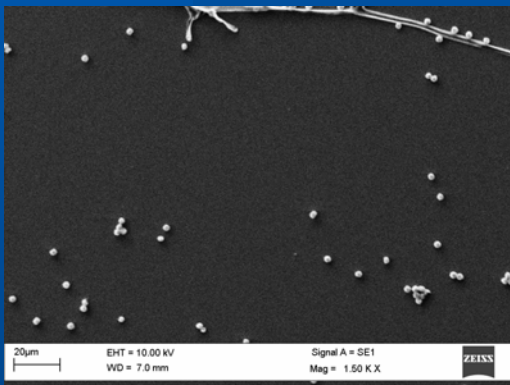
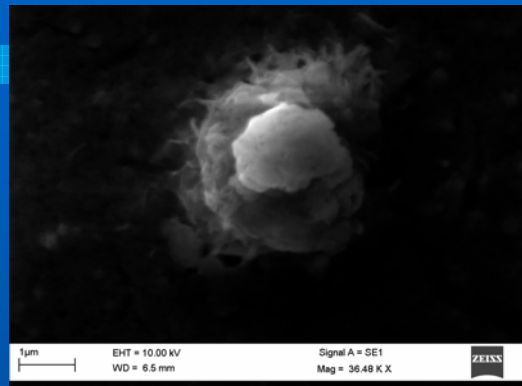
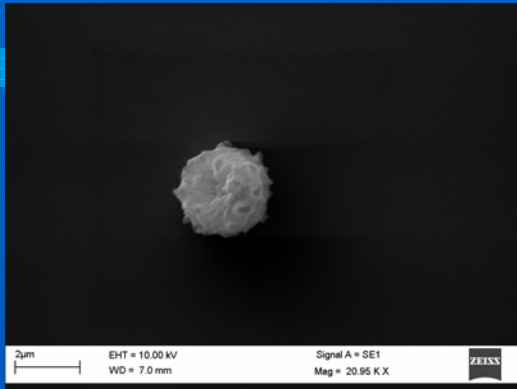




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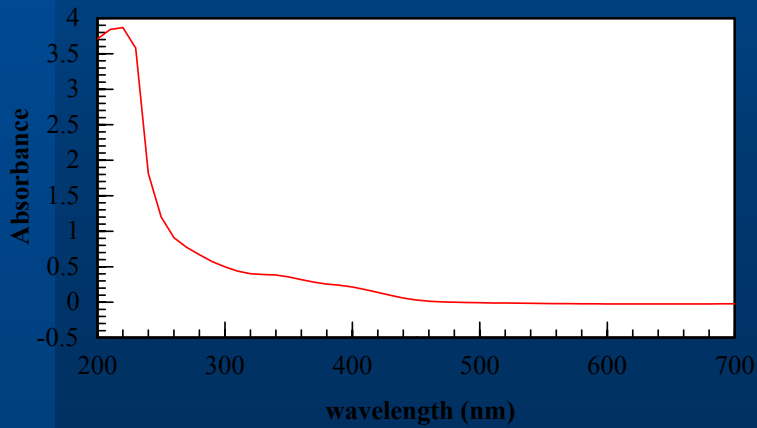
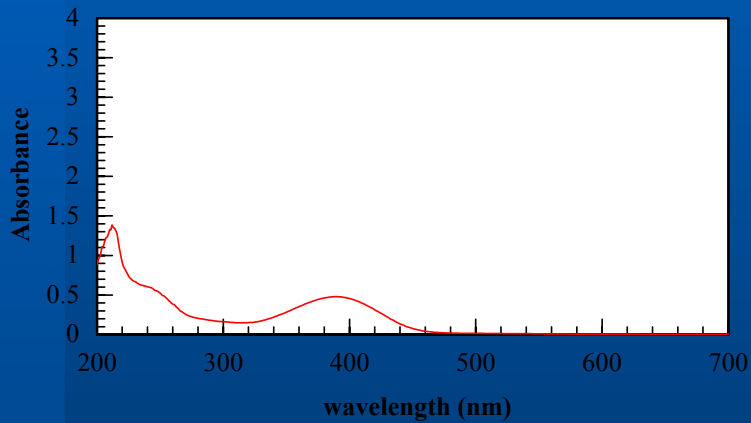
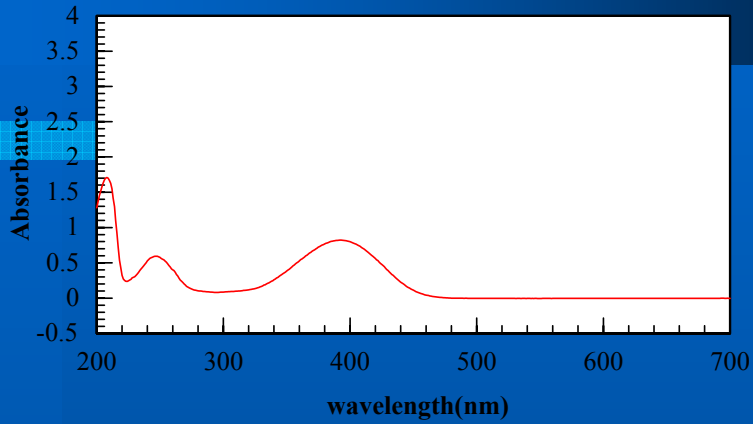
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# SPOR Sterilization in Water



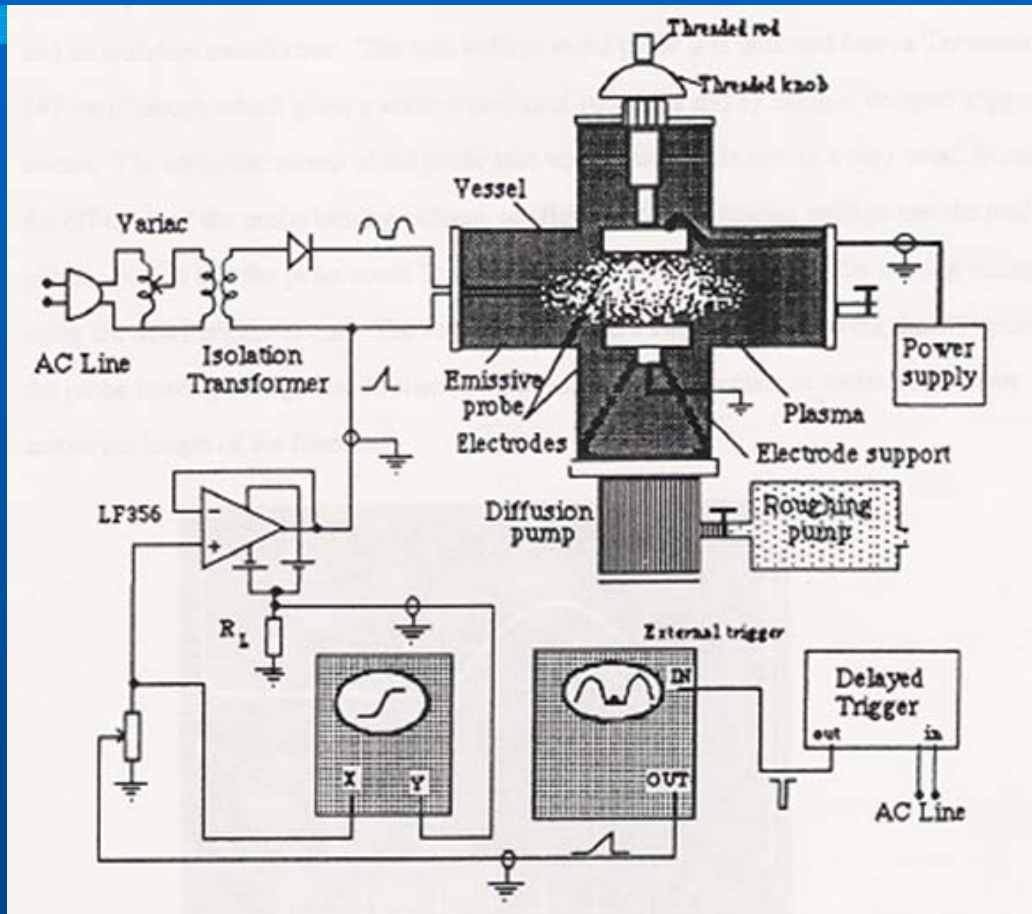


# Textile Dye Conversion





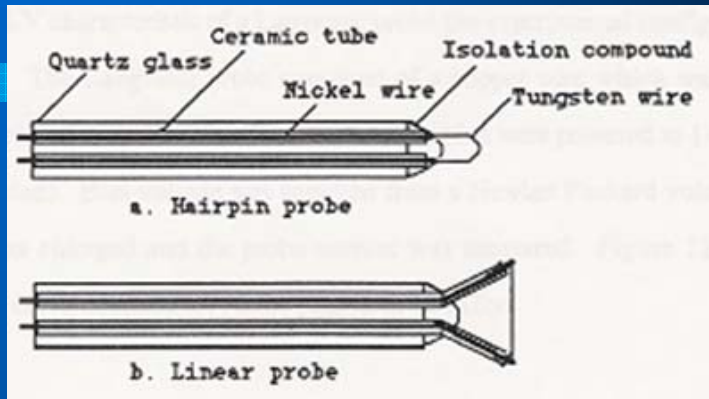
# EMISSIVE & LANGMUIR PROBES for DC-RF GLOW DISCHARGE PLASMA



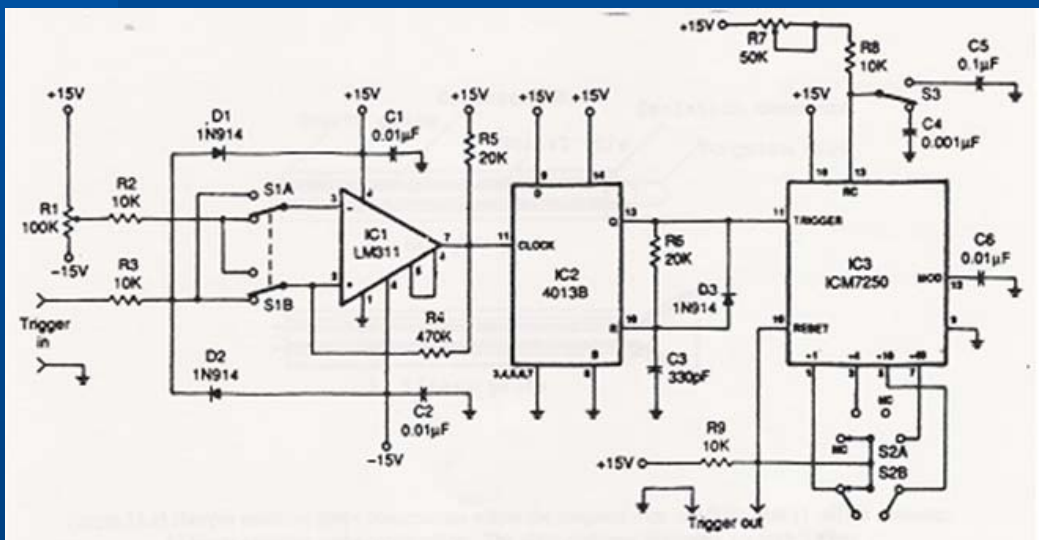
1.4 kV 3-100 mTorr



# Emissive Probe Design

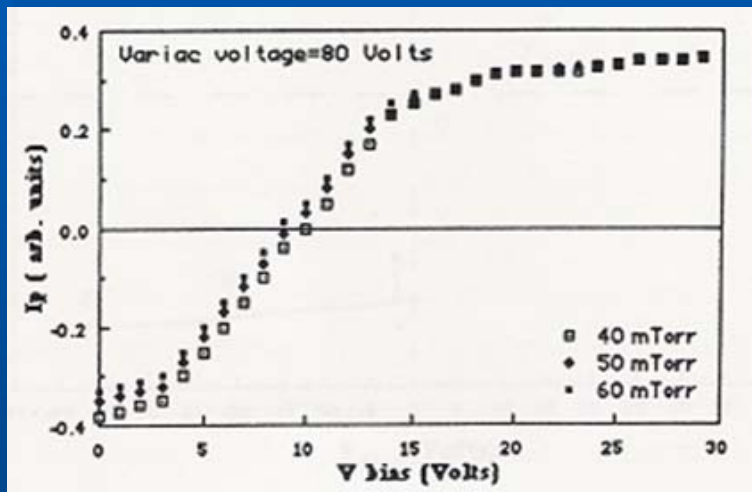
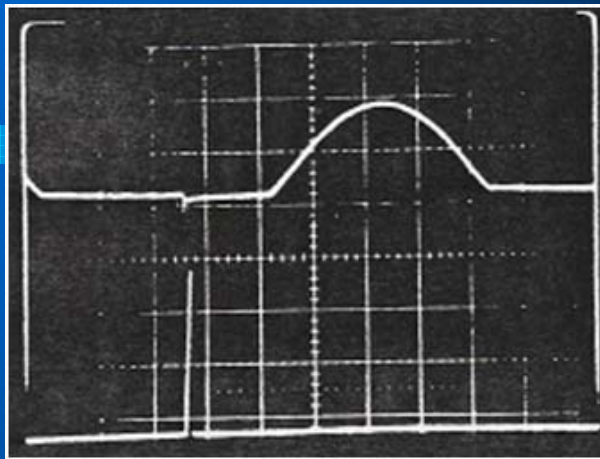


# Delayed Trigger Circuit





# Sweep Voltage for Probe Heating



MEASURE  $\rightarrow n_e$  &  $T_e$



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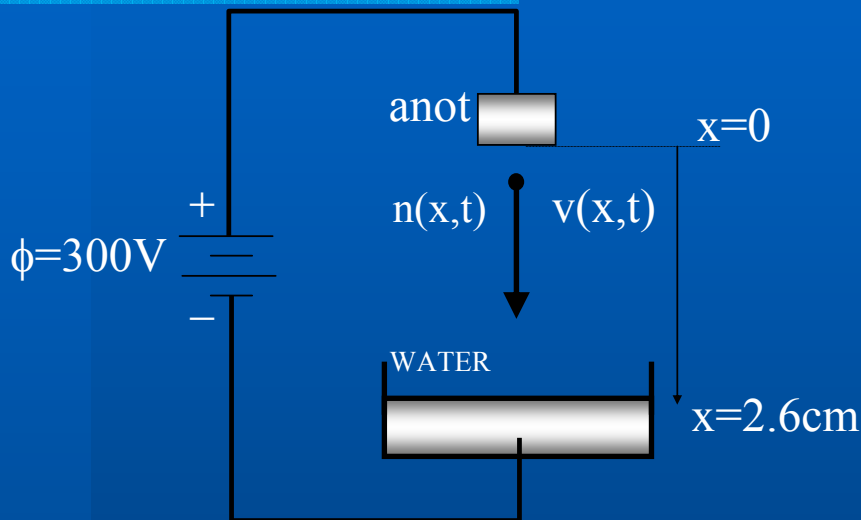
# NEW VACUUM CHAMBER





## 1D CODE

# Numerical Solutions of GLOW DISCHARGE Ion Flux on Surface



$$\frac{\partial n(x,t)}{\partial t} + \frac{\partial}{\partial x} [n(x,t)v(x,t)] = 0$$

$$\frac{\partial v(x,t)}{\partial t} + v \frac{\partial v(x,t)}{\partial x} = -\frac{e}{m} \frac{\partial \phi(x,t)}{\partial x}$$

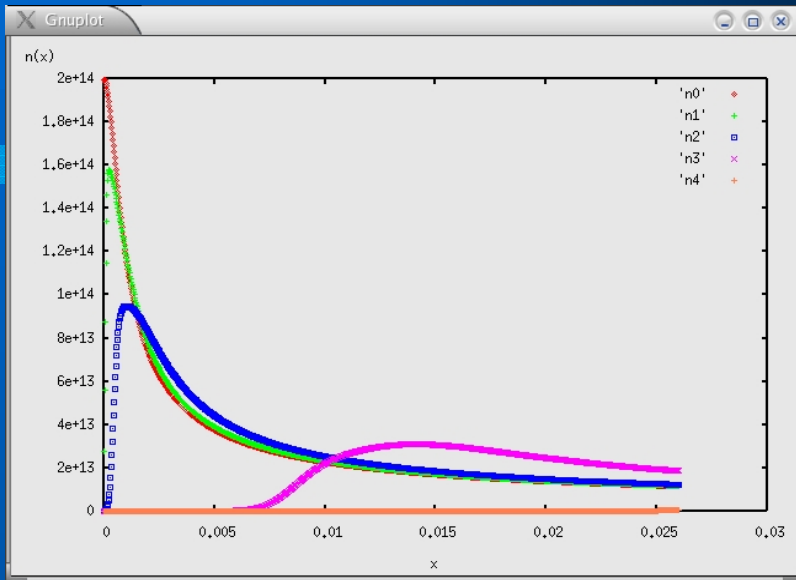
$$\frac{\partial^2 \phi(x,t)}{\partial x^2} = -\frac{e}{\epsilon_0} n(x,t)$$



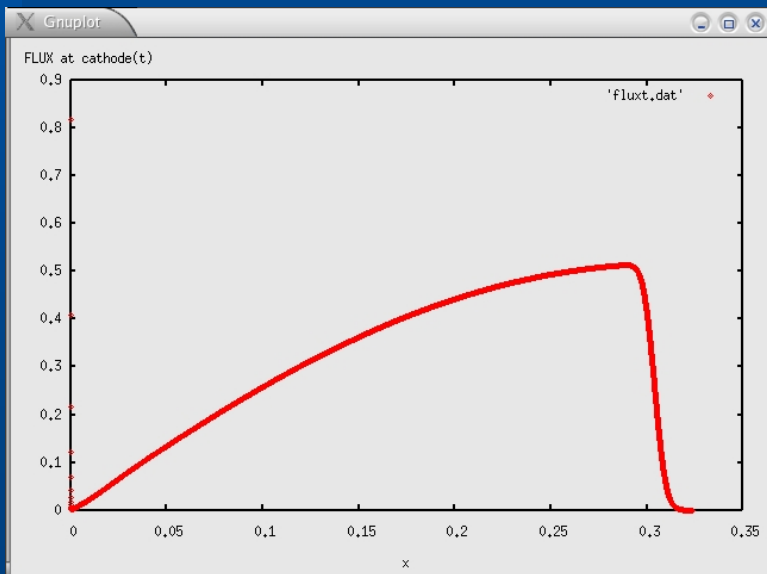
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## Density Profiles



## Ion Flux on Water Surface





## ***2.5 DIMENSIONAL Visual, Parallel Code***

**NOTE: CODE DEVELOPED by US!**

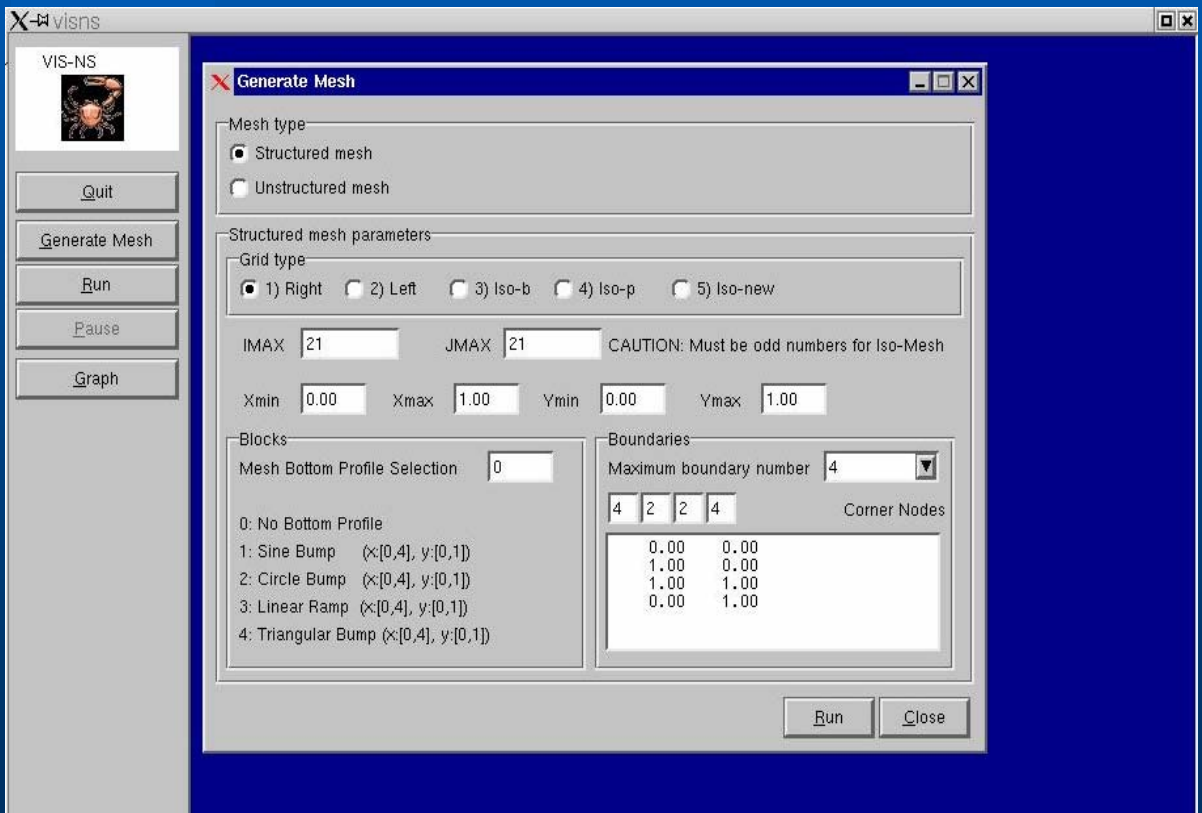
- ✓ Choose NS, MHD, Partially Ionized Plasma, Glow Discharge Modules
- ✓ User friendly GUI,
- ✓ Create complex mesh,
- ✓ Specify any IC and BC,
- ✓ Create color & vector graphs,
- ✓ Run Steady State or Time Dependent problems,



# Properties of the Code

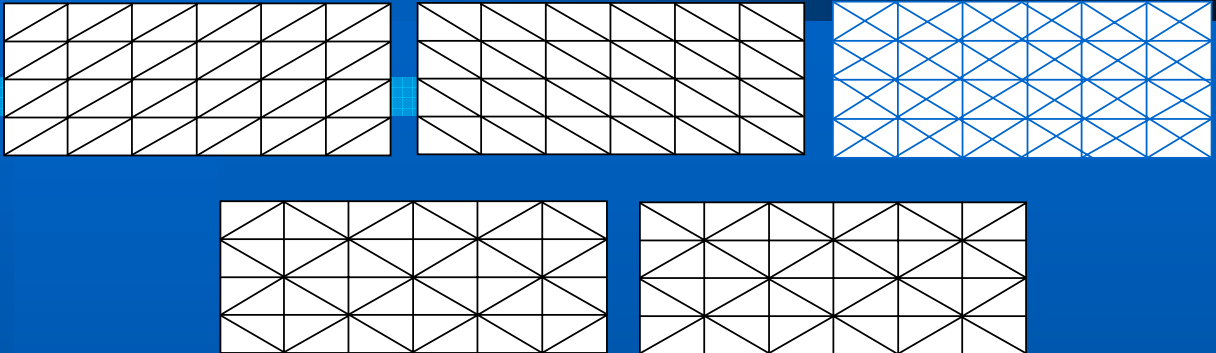
## ✓ Mesh Generation

### Structured/Unstructured Triangular mesh

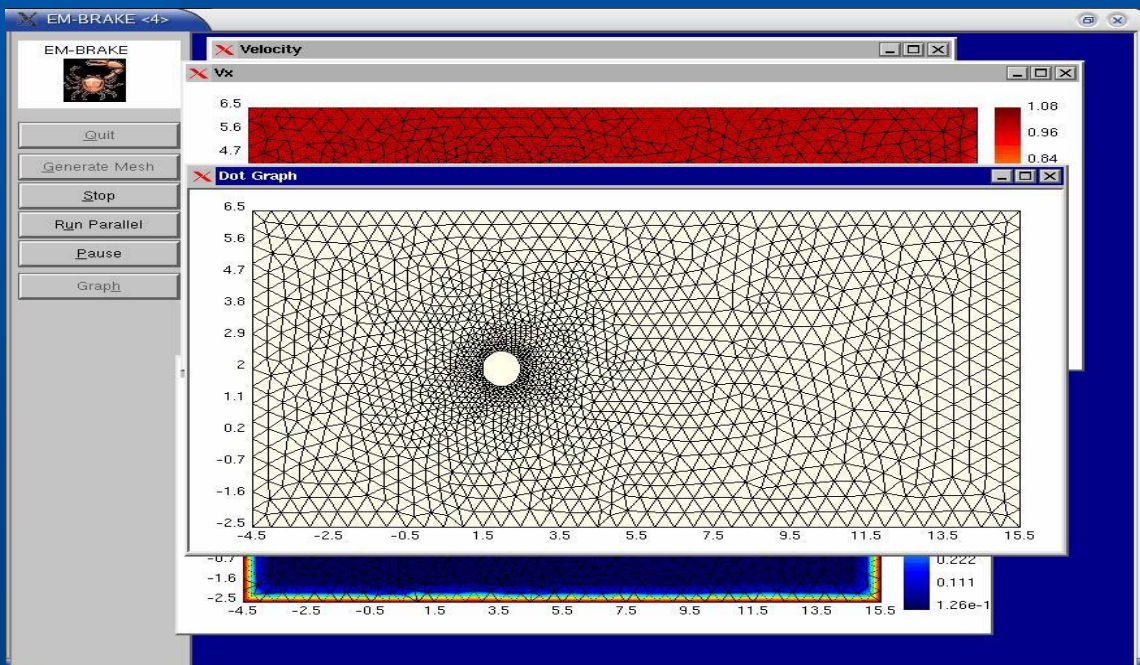




## ✓ Structured Triangular Meshes



## ✓ Unstructured Triangular Meshes





## ✓ Applying the Boundary and Initial Conditions—USER FRIENDLY

Run problem

Problem: Navier Stokes  
Order of R-K Method: 1

Start with data from files

NMAX: 100

Temperature exists  Salinity exists

pconv

Mesh type:  Structured  Unstructured

STEADY? 0/1: 0

Phi (unsteady): 0.5

pinit: 0  
uinit: 0  
vinit: 0  
Tinit: 0

ro: 1  
betasq: 5  
Re: 100  
Ra: 1000.00  
Pr: 0.72  
SIDEsalinity: 1

couran: 2  
maxbnd: 4

BOUNDARY CONDITIONS				
P	U	V	T	S
-10	0	0	1	-10
-10	0	0	0	-10
-10	0	0	0	-10
-10	0	0	0	-10

RA\_T: 5e+06 Le=0.0011  
N=(RaS/RaT)Le: 15  
dt value: 0.05  
Tepylon: 0  
T1: 40 T2: 60 T3: 80 T4: 100

Run Close



# ✓ Graph Selection

**Graphics Options**

Draw graphs

- Vector graph of Velocity
- Color graph of Pressure
- Color graph of Temperature
- Vector graph of Magnetic Field
- Color graph of Density
- Color graph of Beta
- Color graph of Mach Number
- Color graph of Divergence-B
- Max. Div-Error
- L2-Norm
- KE
- VORTICITY
- Energies
- PB
- DIV-V
- Dot Graph

Refresh color graphs at each  steps

Refresh vector graphs at each  steps

Maximum vector length

Display mesh

visits

VIS-NS

**Pressure**

**Temperature**

**L2-Norm**

**Div-Error**

**Velocity**

**Run Screen**

```
35 D1v=6.77485 Res=-2.41204
36 D1v=7.86054 Res=-2.33842
37 D1v=7.95661 Res=-2.29058
38 D1v=7.7103 Res=-2.26782
39 D1v=7.04607 Res=-2.26703
40 D1v=6.13134 Res=-2.26681
41 D1v=6.26268 Res=-2.32142
42 D1v=6.19867 Res=-2.36517
```



# **Compressible MHD EQUATIONS**

## CONSERVATION OF MASS

$$\frac{\partial \rho}{\partial t} + \vec{\nabla} \cdot [\rho \vec{V}] = 0$$

## CONSERVATION OF MOMENTUM

$$\frac{\partial \rho \vec{V}}{\partial t} + \vec{\nabla} \cdot \left[ \left( P + \frac{B^2}{8\pi} \right) \vec{I} - \rho \vec{V} \vec{V} - \vec{B} \vec{B} \right] = 0$$

## CONSERVATION OF ENERGY

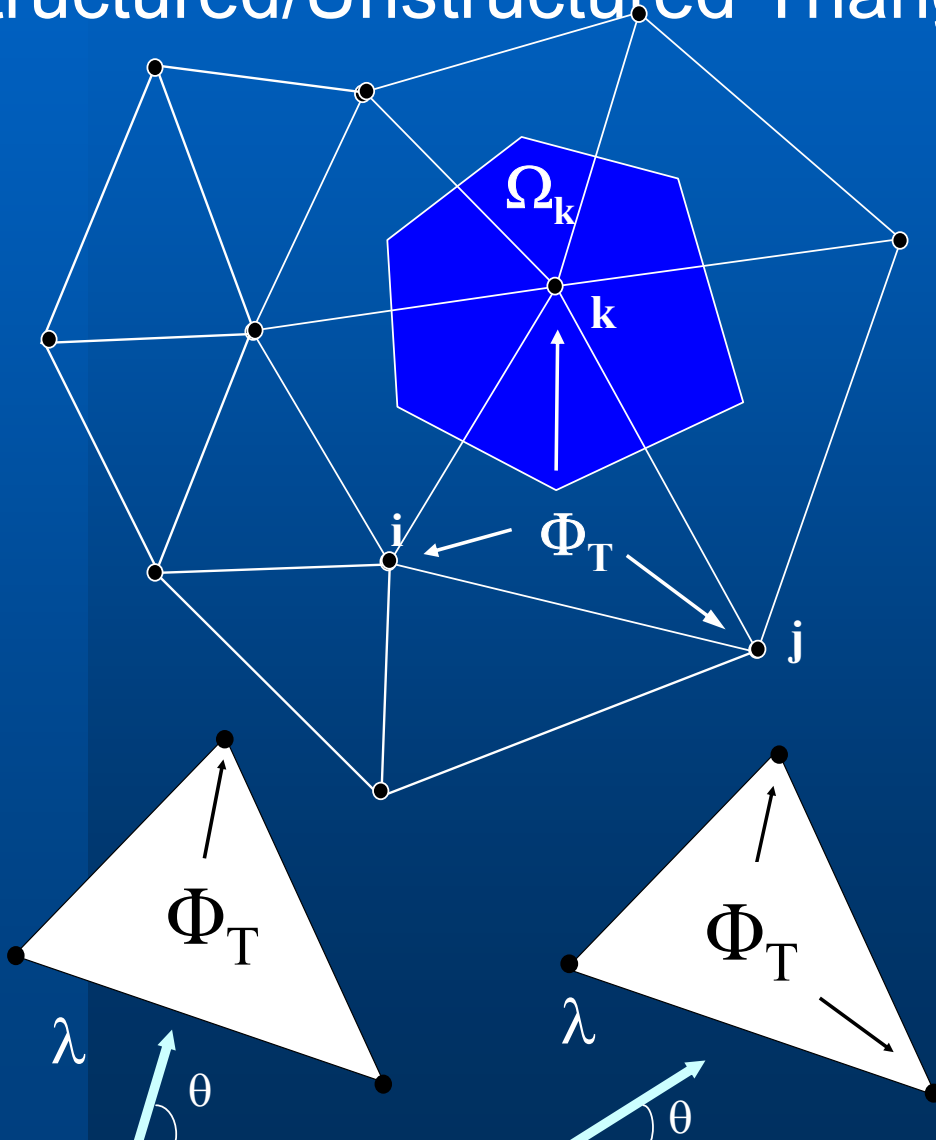
$$\frac{\partial E}{\partial t} + \vec{\nabla} \cdot \left[ \left( E + P + \frac{B^2}{8\pi} \right) \vec{V} + \frac{\vec{B}}{4\pi} (\vec{V} \cdot \vec{B}) \right] = 0$$

$$E = \frac{p}{\gamma - 1} + \frac{1}{2} \rho V^2 + \frac{B^2}{8\pi}$$



**NUMERICAL METHOD on  
TRIANGULAR MESH & WAVE MODEL**

**Fluctuation Distribution on  
Structured/Unstructured Triangles**





## *Incompressible viscous and resistive MHD EQUATIONS*

$$\vec{\nabla} \cdot \vec{V} = 0 \quad , \quad \vec{\nabla} \cdot \vec{B} = 0$$

$$\frac{\partial \vec{V}}{\partial t} + \vec{V} \cdot \vec{\nabla} \vec{V} + \frac{\vec{\nabla} P}{\rho} = \nu \nabla^2 \vec{V} - \rho \vec{g} + \frac{\vec{J}_T \times \vec{B}}{\rho}$$

$$\frac{\partial \vec{B}}{\partial t} + \vec{\nabla} \cdot \left[ \begin{array}{cc} \vec{B} & \vec{V} \\ \vec{V} & \vec{B} \end{array} \right] = \frac{1}{\mu_0 \sigma} \nabla^2 \vec{B}$$

$$\rho C_v \left( \frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} \right) = k \nabla^2 T + \frac{J_T^2}{\sigma}$$

$$\vec{J}_T = \sigma \left( \vec{E}_{ext} + \vec{V} \times \vec{B}_{ext} \right) + \vec{J} \quad , \quad \vec{J} = \frac{\vec{\nabla} \times \vec{B}}{\mu_0}$$



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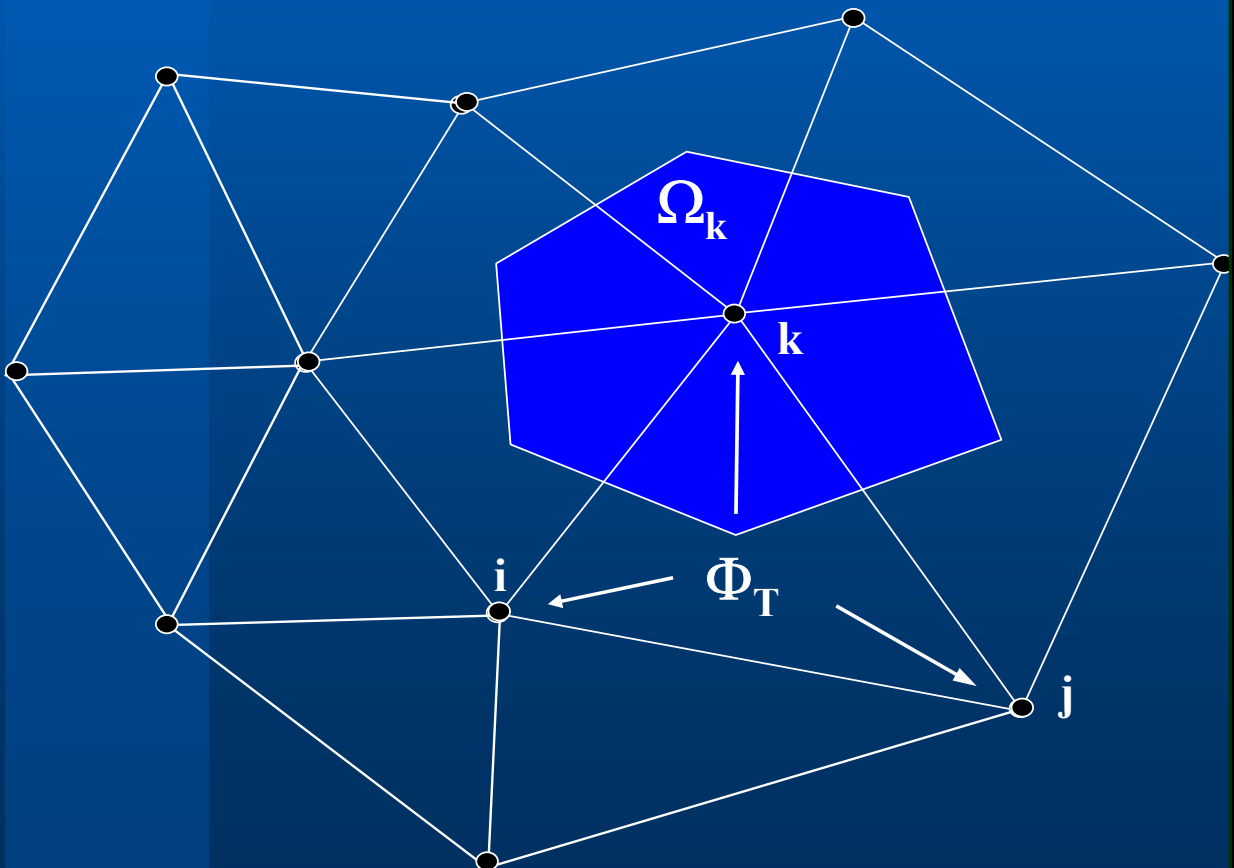
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## ***NUMERICAL METHOD on TRIANGULAR MESH***

**MATRIX Distribution on  
Structured/Unstructured Triangles**

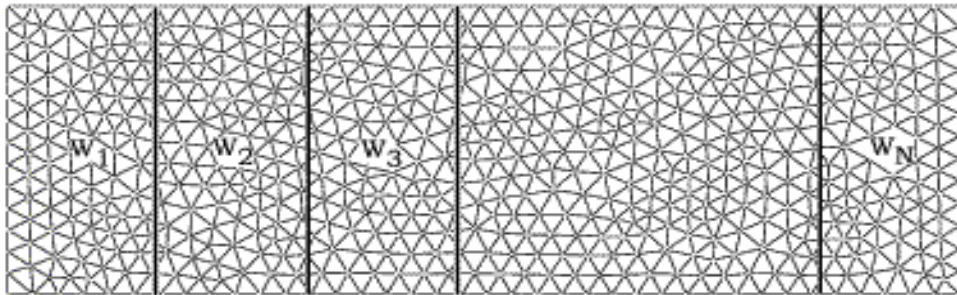
**Similar to FEM but more efficient & stable**

**Phillip Roe & von Karman Institute**

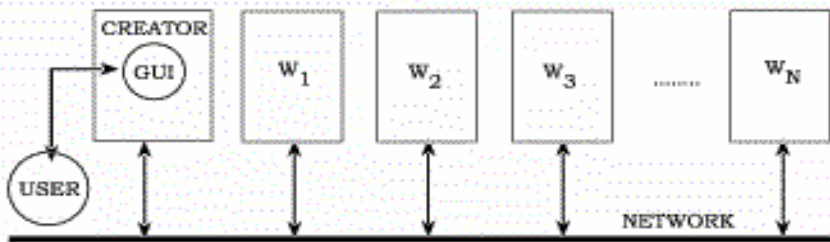




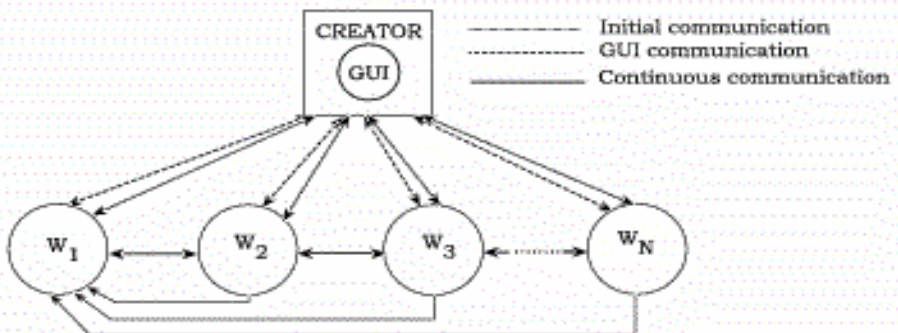
# PARALLEL PROCESSING



(a)



(b)



(c)

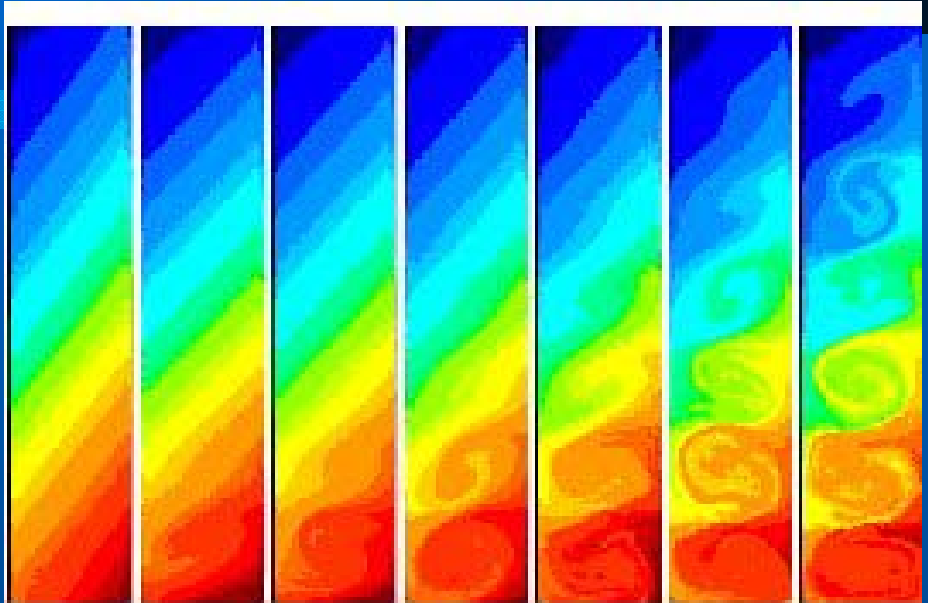


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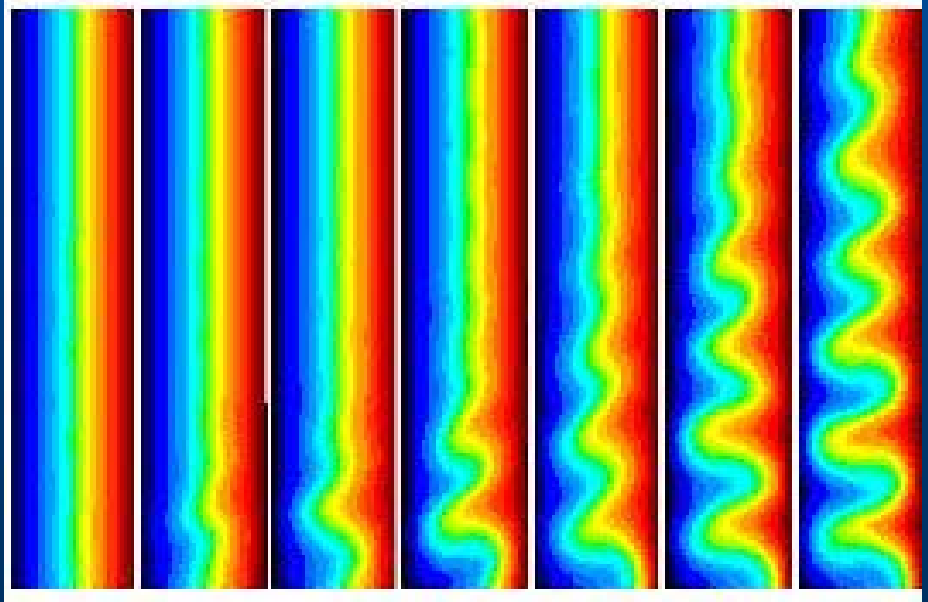
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# *DOUBLE DIFFUSIVE FLOWS SALT FINGER INSTABILITY*

*SALINITY*



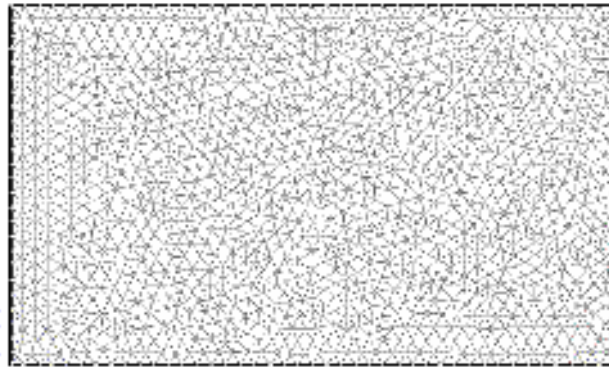
*TEMPERATURE*



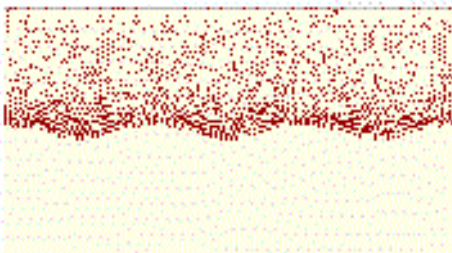


# *Rayleigh-Taylor Instability*

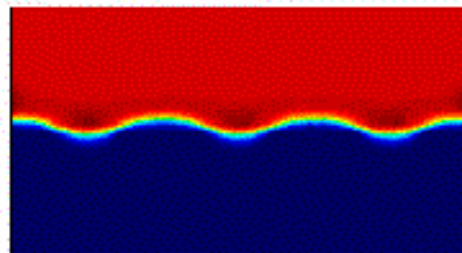
## *PIC: PARTICLE IN CELL FEATURE*



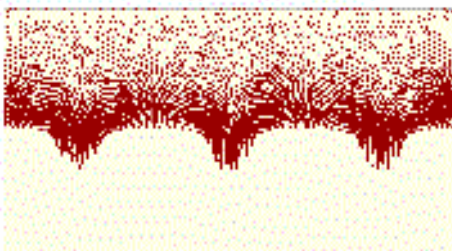
(a) Unstructured Mesh



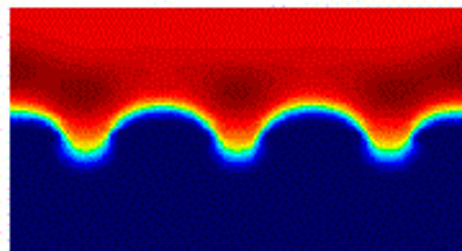
(b) PIC screen at  $t=1$



(c) Density at  $t=1$



(d) PIC screen at  $t=2$

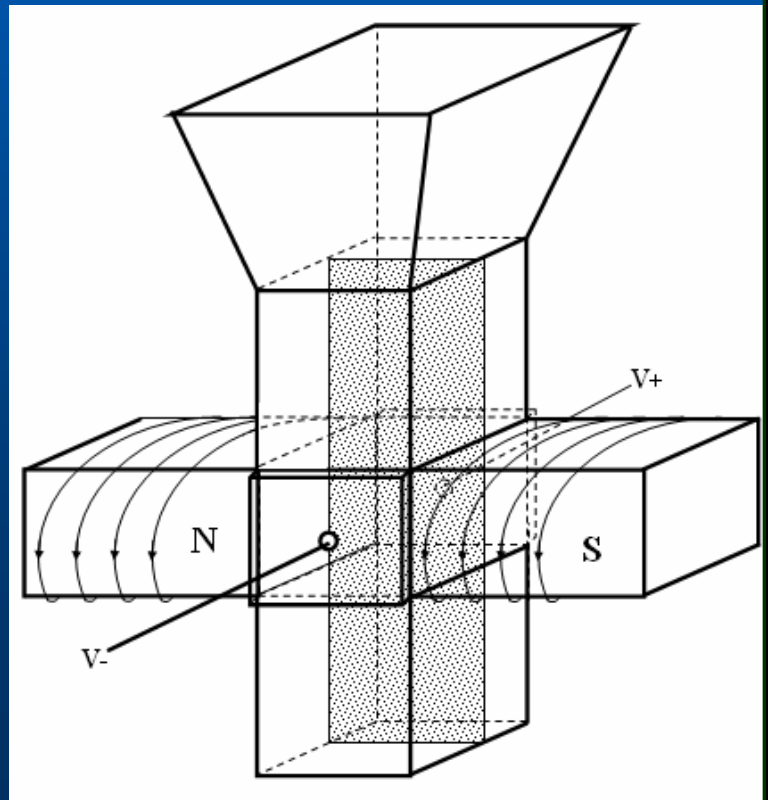
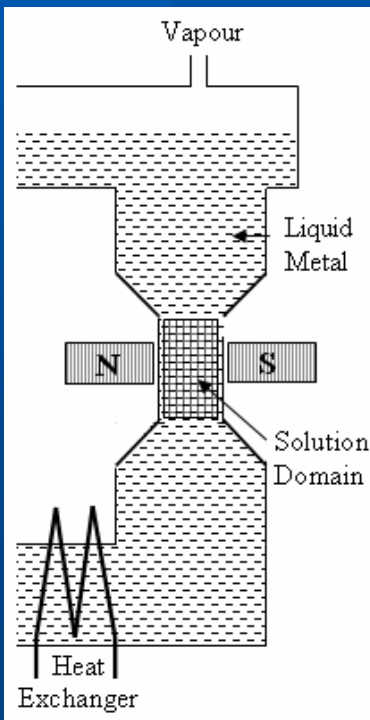


(e) Density at  $t=2$



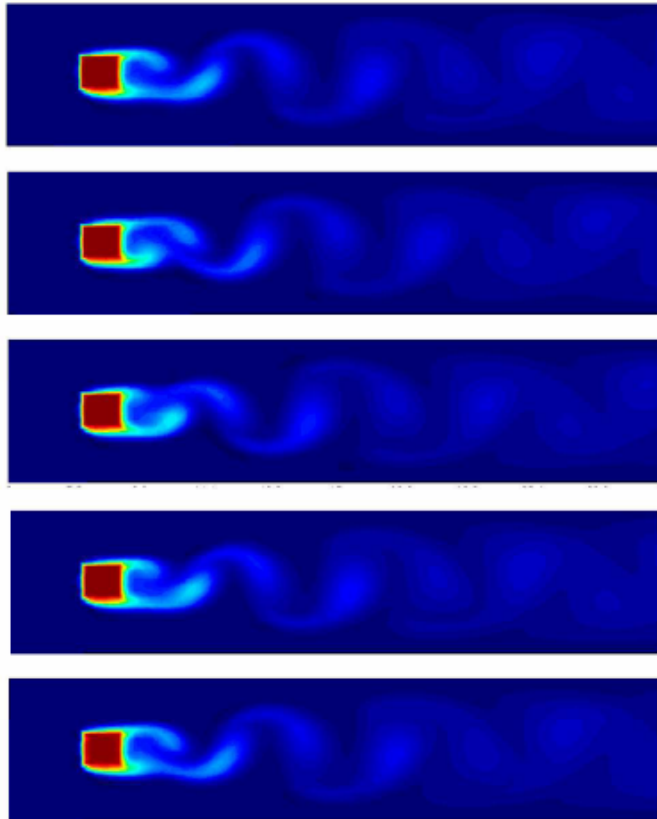
# NUMERICAL TESTS

## 6. ELECTROMAGNETIC BRAKING TEST





## ***TWO+1/2 DIMENSIONAL CODE***

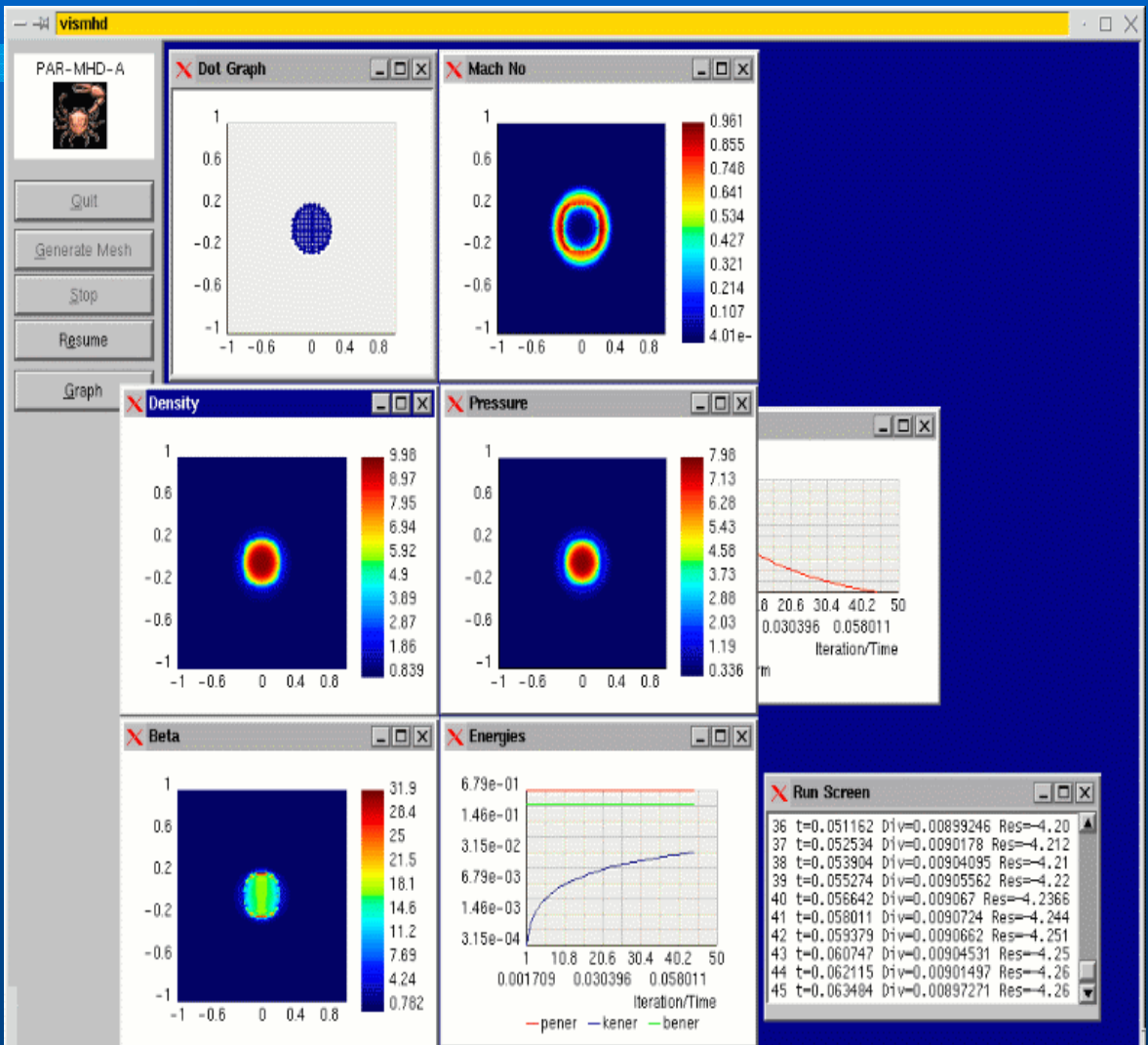


The temperature color graphs for a flow around heated electronic component for  $Re = 250$  and  $Pr = 0.71$  at times,  $t = 156.2, 157.6, 159, 160, 161$  from top to the bottom.

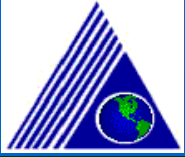
***Test: Flow over Heated Electronics Component***



# TWO+1/2 DIMENSIONAL CODE screen view



**Test: Discharge X-Section Sudden Expansion**



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## **CONCLUSION**

- ✓ **Develop Efficient and CHEAP plasma systems**
- ✓ **Low Temperature Sterilization**
- ✓ **Various Electronics & Robotics Applications**
- ✓ **GOAL: Numerical 3D calculations (mesh generation algorithm OK)**
- ✓ **GOAL: Develop an automatic vacuum system for BIO-SENSOR development**
- ✓ **GOAL: Anaerobic Bacteria Elimination from teeth by modular plasma probe**

**THANK YOU**

**[naslan@yeditepe.edu.tr](mailto:naslan@yeditepe.edu.tr)**