3.37 (Class 19)

Review

- 80-90% of heat to the anode is carried by the electrons
- There is a large voltage drop (3-5V) at the anode and cathode regions where the temperature is lower

Today

Plasmas and the properties of plasmas

Plots on overhead (from packet)

Temperature of the gas vs. pressure
- Welding arc is a "high-pressure" plasma
- Local thermodynamic equilibrium (LTE), physicists love to debate if this is really true
- At pressures above 0.1 to 0.3 atm, called a high pressure arc
- Temperature on the order of 10^4, 20000-30000K
- Can't have a stable arc above about 30 atm (aside, this is equiv to about 1000' depth, can only do underwater welding with electric arcs to about this depth)

Fluorescent light
- At approx .1 to 1mm Hg
- Temperature of electrons much higher than temperature of ions and neutrals
- Charged particles in electric field, electrons have low mass, they get accelerated to much higher velocities, velocity is proportional to the temperature, electrons generate the light, two temperature plasma

Welding Current vs. Voltage of the Arc
- Fluorescent light several thousand volts, "glow"
- Strike an arc in a vacuum, can trace this curve on an oscilloscope

Lots of research on arcs
- Head of GE Research Lab studied lots about arcs
- Prof of Physics at MIT, Carl Taylor Thompson
- Development of circuit breakers to extinguish arcs

How heat is transferred to the workpiece
- Heat to the Anode
- Diagram on board, tip is cathode, electrons from cathode to workpiece

- Qheat = Qelectrons + Qconvection + Qconduction + Qradiation
  =I(work function voltage + anode voltage drop + Thompson voltage (thermal energy of electrons)) + Qcond + Qconv + Qrad
- 80-90% is Qelectrons
- Qrad about ½%, Qcond about 4-5%, Qconv about 4-5%
- Planck curve, eyes see intense radiation from arc, but surface radiates more, get a sunburn just as bad from the hot weld pool
- Work function
  - typical ref point for electrons is a free stationary electron in a vacuum, has a lower energy (at the Fermi energy), this difference is the work function, phi
  - Graph from notes on overhead
  - Can be up to about 7-8V
- Thermal energy, due to being hot, $V_t = (3/2)kT/e$, 25mV at 300K, at 10000K about 1.2V, on the order of 1-2V
- Anode voltage drop 4-5V
- Total voltage about 13V

Asymmetry, have a cooling effect at cathode, (heat of vaporization of the cathode) while heating effect at the anode
- About 30% at the cathode
- About 70% at the anode
  - How do we know this is true, in Gas Tungsten Arc typically use electrode as negative, since don't want to melt the electrode, if switch polarity around can only run at much lower current (say ½) before tungsten melts
  - DC electrode negative (DCEN) or straight vs. DC electrode positive (DCEP) or reverse

Typical voltage gradients are 10^8 V/cm

Different Welding Processes
- TiG, Gas Tungsten Arc Welding, DCEN straight, try to melt base metal but not electrode so choose the polarity accordingly
- Gas Metal Arc Welding, DCEP, or reverse, want to melt the electrode to fill the weld, so want the heat on the electrode
  - for copper, Hitachi developed special welding power supplies, special AC welding machine to change polarity, electrode positive to melt the copper electrode, electrode negative to heat the base plate, square wave with varying duty cycle to balance the heat between the two
- Often use AC to weld aluminum, AC balance control, get cleaning action

Argon
- Roughly 1% of the air, relatively cheap and available
- Can use nitrogen, but not for steel since creates porosities in steel
- Ar: Qelec = 90%, Qcond/conv/rad = 10%

He

- Most from natural gas wells in Southern United States, world price of helium is about 10x the US price
- Higher ionization potential, in the welding handbook this was the theory for why a higher temperature, this is wrong, this doesn't explain it. The explanation is that He has three times the thermal conductivity of Ar
- He: Qelec = 90%, Qcond/conv/rad = 30%, equals 120% of the heat if switch gas to helium
- Few parts of the world can afford to do this, in the US this is feasible
- Rest of the world often uses ArH2