Penning transfers:

survey of available data, life-time of excited states, pressure dependence

Ozkan SAHIN
Uludag University Physics Department
Bursa -TURKEY

Introduction

- **Mixtures used in proportional counters:**

  Ne, Ar, He …. + Methane, Ethane, Isobutane …

- **Non-ionising interactions:**

  UV photons emitted from excited states

- **High gas gains (up to 10^6):**

  before reaching a continues discharge

Penning effect

- **Excited noble gas atoms can transfer their energy:**

  if they do not decay before collisions !!!

- **Excitation energy > ionisation energy of admixture:**

- **Number of the generated electron-ion pairs increase:**

  low W and F in the mixtures

  improvement in the detector energy resolution

Investigated Penning gas mixtures

1- **Argon – Ethane**

2- **Argon – Isobutane**

3- **Argon – Propane**

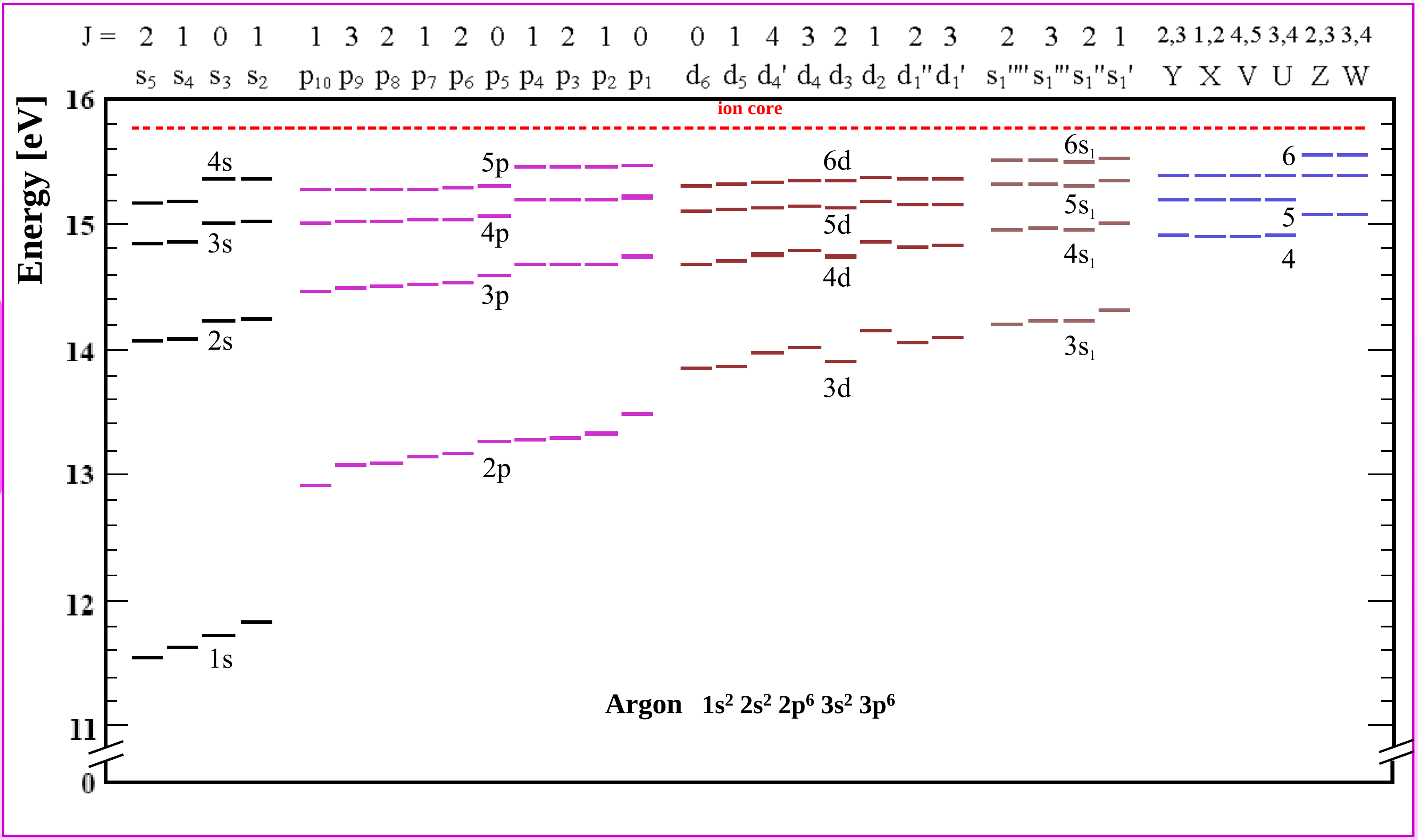
4- **Argon – Methane**

5- **Argon – Acetylene**

6- **Argon – CO_2**

7- **Argon – Xenon**

Schematic view of the energy levels for Argon I



Methodology

- **A computer program has been developed:**

  single wire proportional counter

- **Gas gain:**

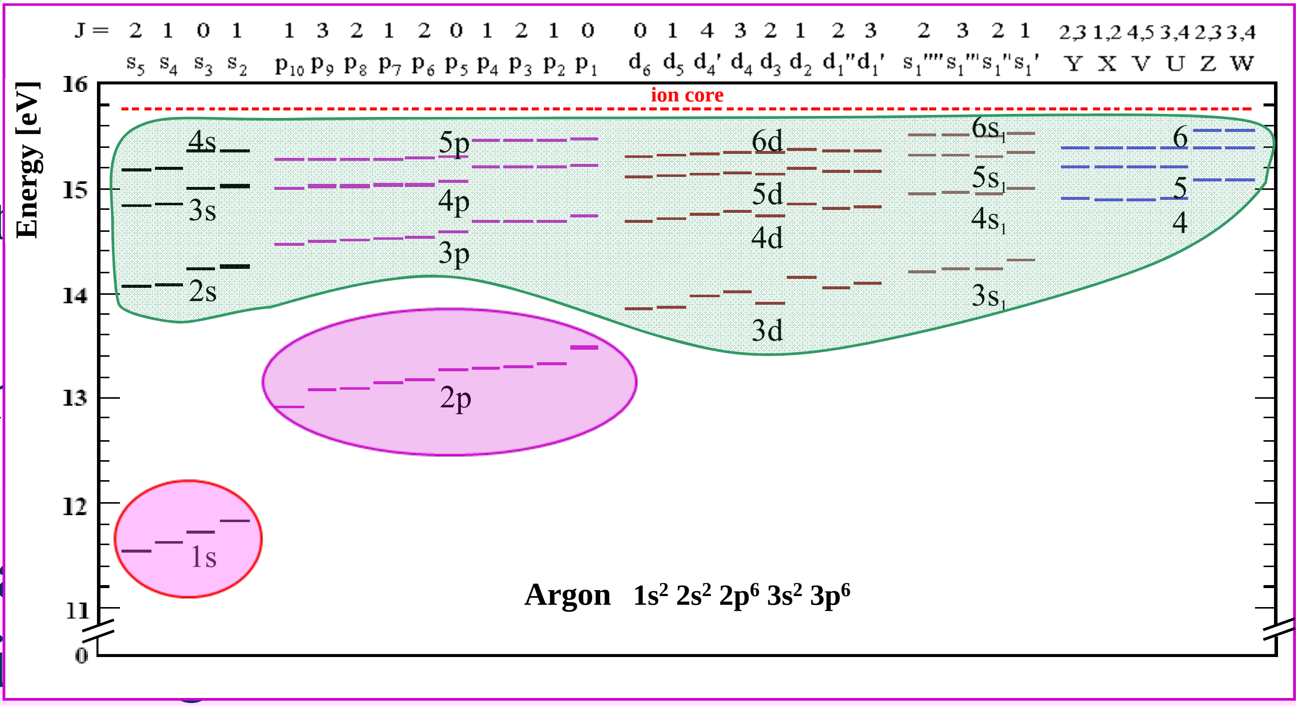
$$G = e^{\int_{r_a}^{r_b} \alpha(E(r)) * dr}$$

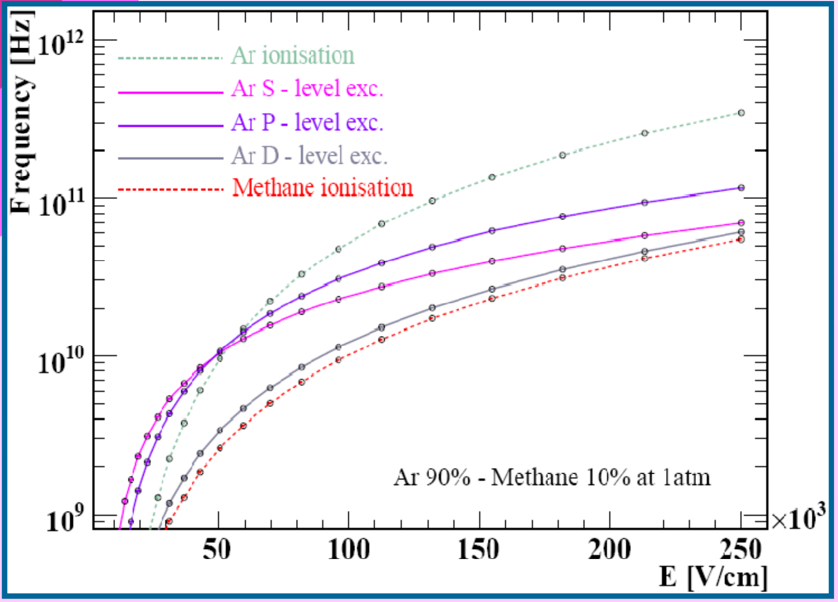
- **Electric field strength *E(r)* at the radius *r* :**

$$E(r) = \frac{V}{r \log(r_a / r_c)}$$

Magboltz:

- To find Townsen
- Magboltz does n
- But, it gives deta and ionisations i





S - level exc. (11.55 eV) → 1s excited levels
P - level exc. (13.0 eV) → 2p excited levels
D - level exc. (14.0 eV) → combinations of s, p, d excited levels

$\alpha_{Penning}$

Using this information a ***Penning-corrected*** ionization coefficient ($\alpha_{Penning}$) for ***all energetically allowed*** Penning transfers can be given by:

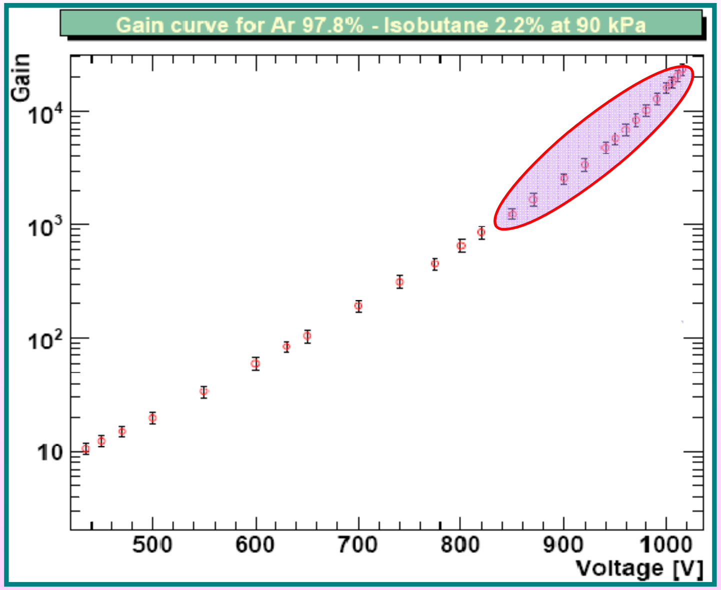
$$\alpha_{Penning} = \alpha \frac{(f_{ion(Ar)} + f_{ion(admix.)} + \sum_i (P(i) * f_{exc\_Ar}(i))}{(f_{ion(Ar)} + f_{ion(admix.)})}$$

Here Penning transfer probability P is defined as the fraction of the energy in the excited states that will cause further ionisations by the Penning processes.

Since this energy transfer fraction is *a priori not known*, the experimental data are used as a guide. P is found by a fitting procedure that achieves the matching between the gains calculated from $\alpha_{Penning}$ and the measured gains.

Photon feedback term

- **Over-exponential growth at high potentials:**
  secondary avalanches due to insufficient quenching of UV photons



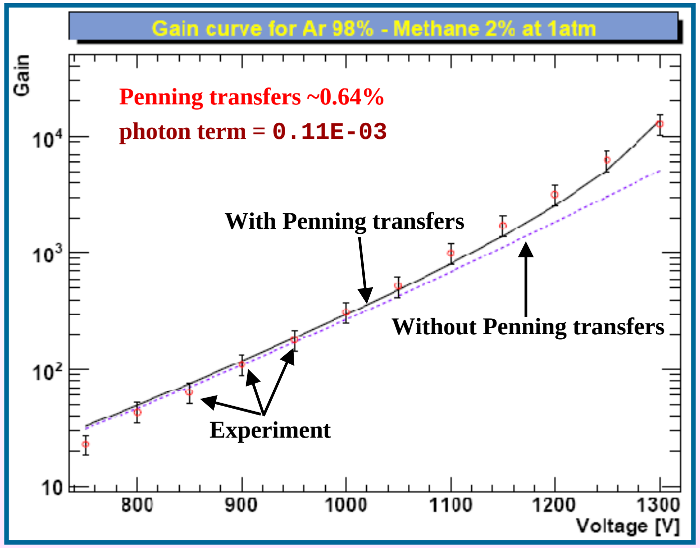
- **G_{total} :**
  including photon feedback

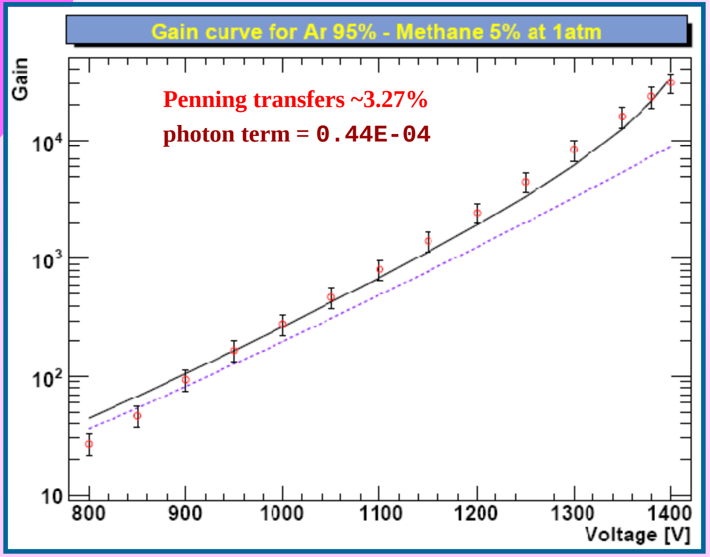
$$G_{tot} = \frac{G}{1 - P_\gamma * G}$$

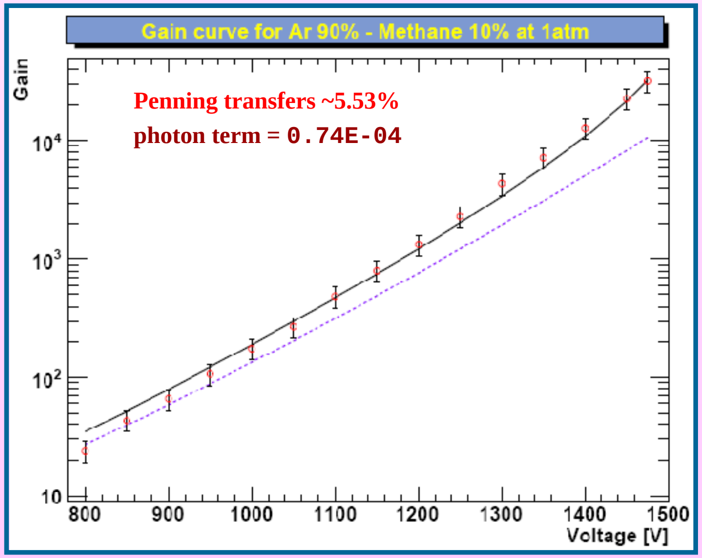
Pγ is the probability that an ionisation in the primary avalanche produces a photon which leads to a secondary avalanche.

Argon – Methane mixtures

$I_{Methane}$ = 12.99 eV
Possible Penning Tranfers: Ar* (P, D level exc.) ⟶ CH_4
Ar + 2%, 5%, 10% Methane

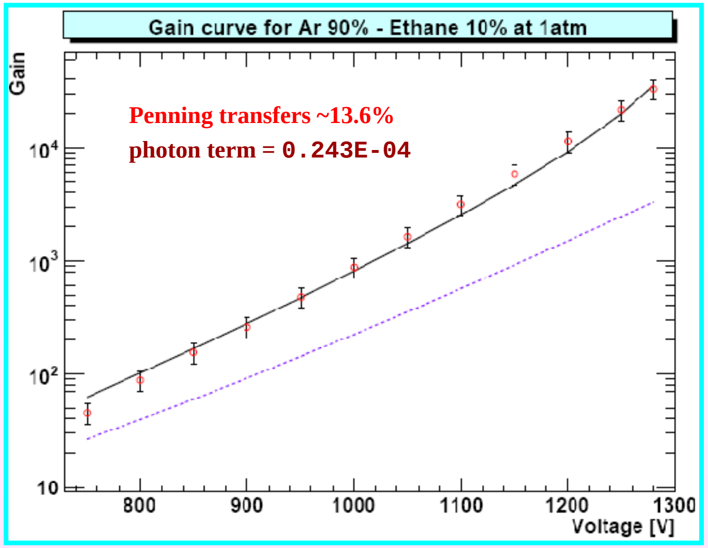






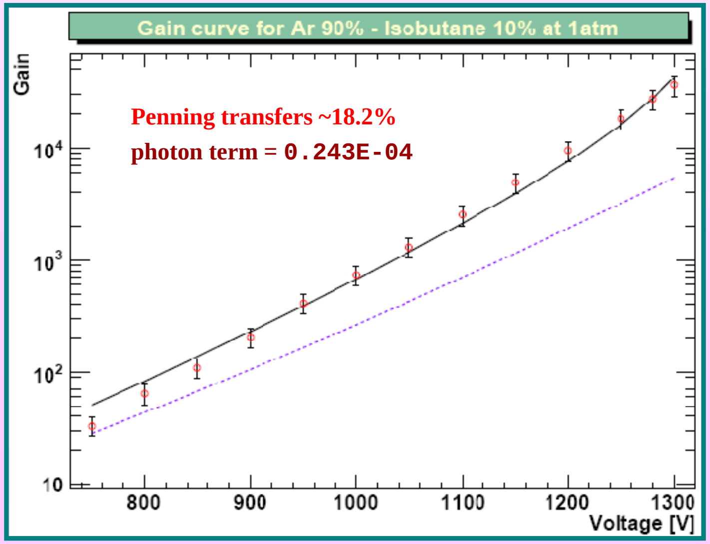
Argon – Ethane mixture

I_{Ethane} = 11.52 eV
Possible Penning Tranfers: Ar* (S, P, D level exc.) ⟶ C_2H_6



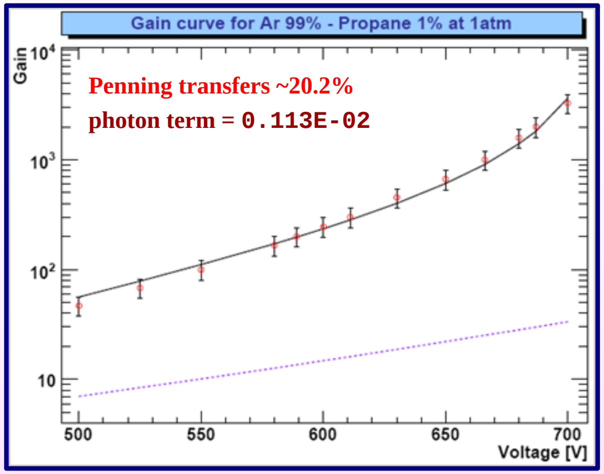
Argon – Isobutane mixture

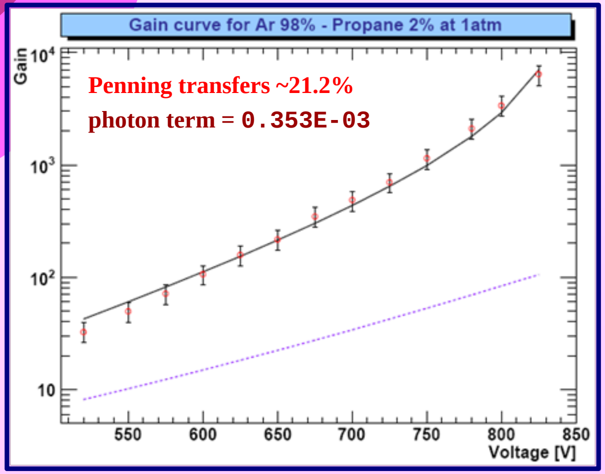
$I_{Isobutane}$ = 10.67 eV
Possible Penning Tranfers: Ar* (S, P, D level exc.) ⟶ iC_4H_{10}

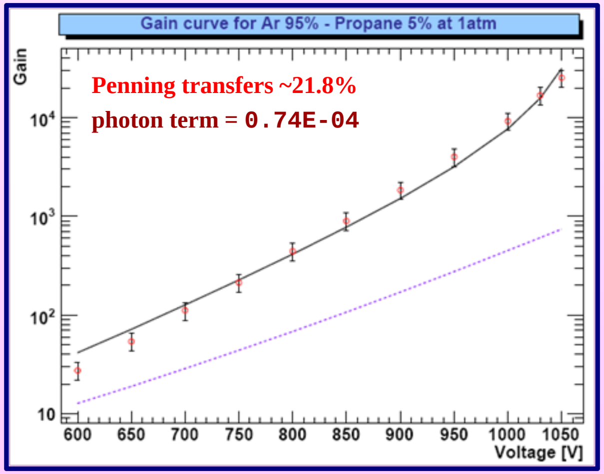


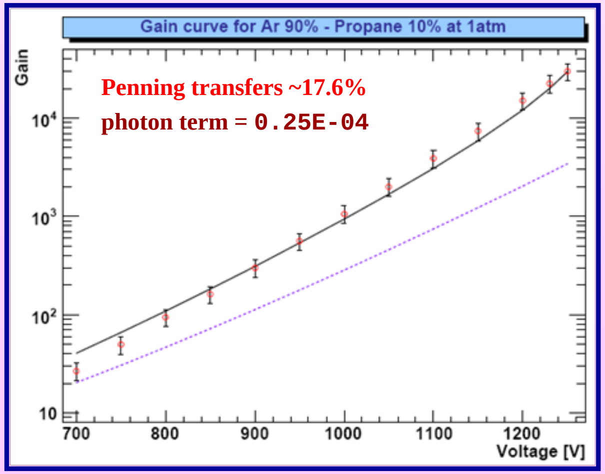
Argon – Propane mixtures

$I_{Propane}$ = 10.95 eV
Possible Penning Tranfers: Ar* (S, P, D level exc.) ⟶ C_3H_8
Ar + 1%, 2%, 5%, %10 Propane



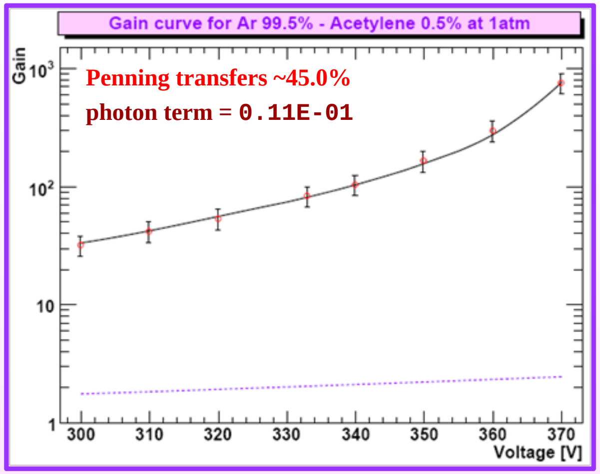


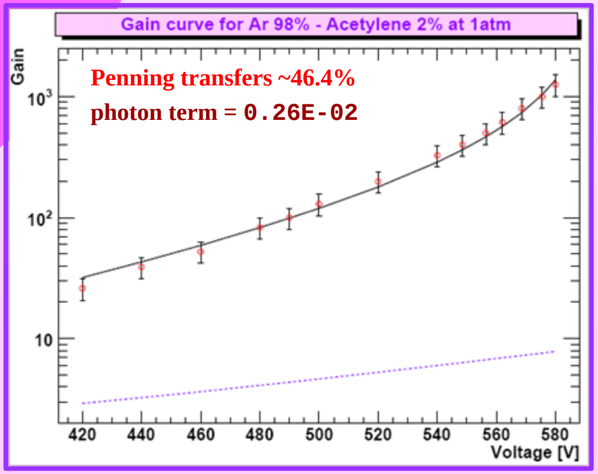


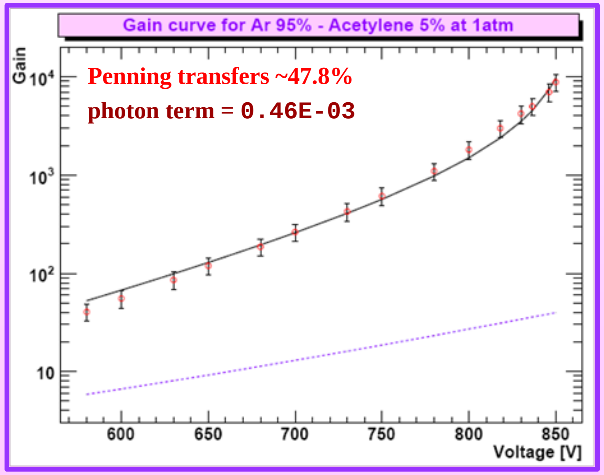


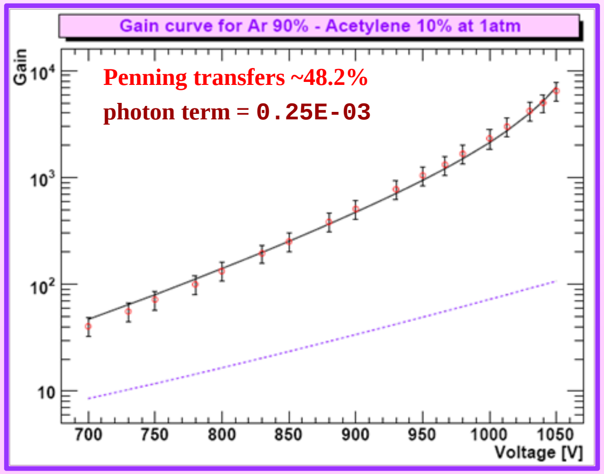
Argon – Acetylene mixtures

$I_{Acetylene}$ = 11.42 eV
Possible Penning Tranfers: Ar* (S, P, D level exc.) ⟶ C_2H_2
Ar + 0.5%, 2%, 5%, 10% Acetylene



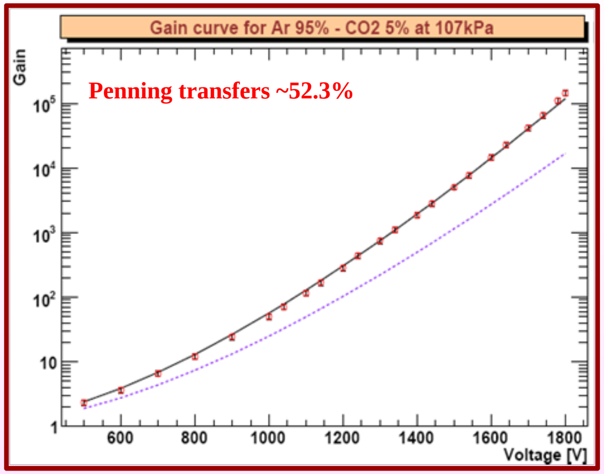


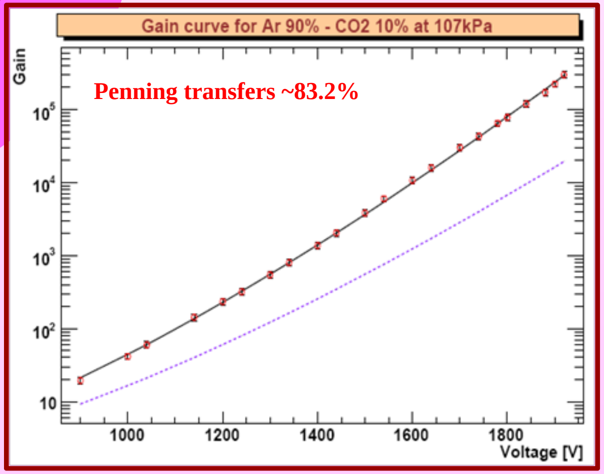


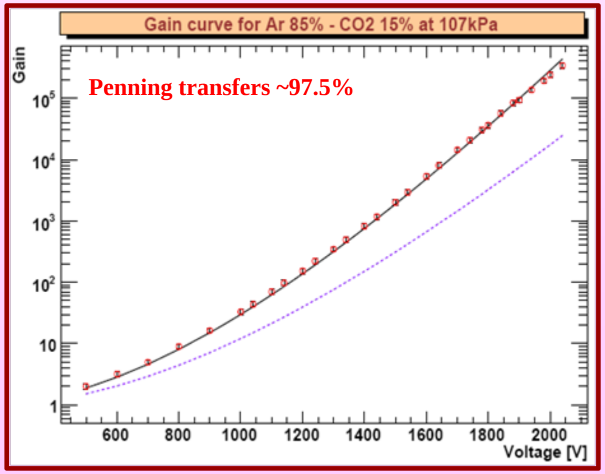


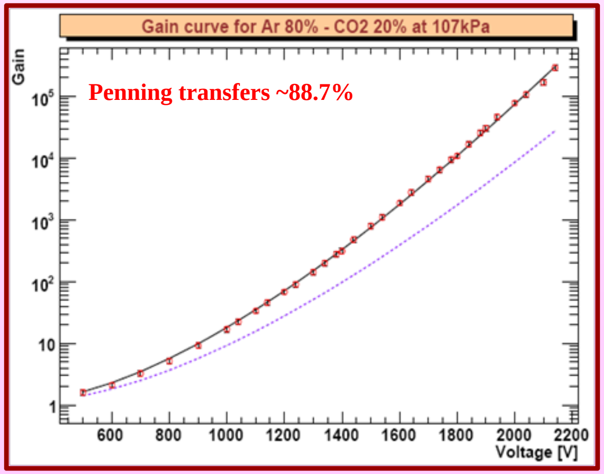
Argon – CO_2 mixtures

I_{CO2} = 13.77 eV
Possible Penning Tranfers: Ar* (only D level exc.) ⟶ CO_2
Ar + 5%, 10%, 15%, 20% CO_2









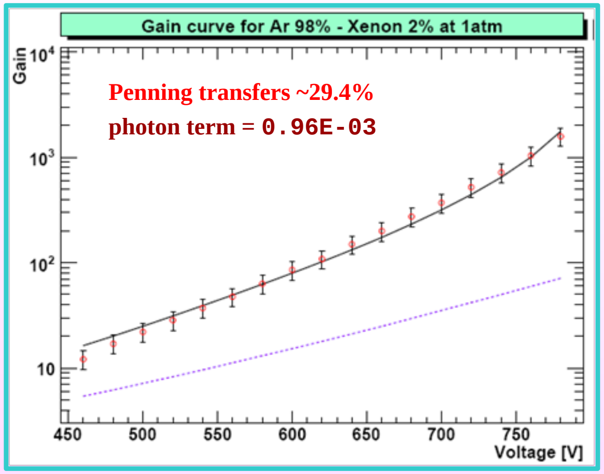
Argon – Xenon mixtures

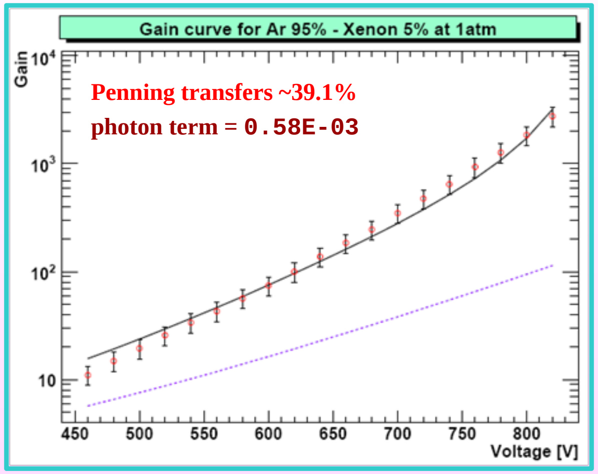
I_{Xenon} = 12.13 eV

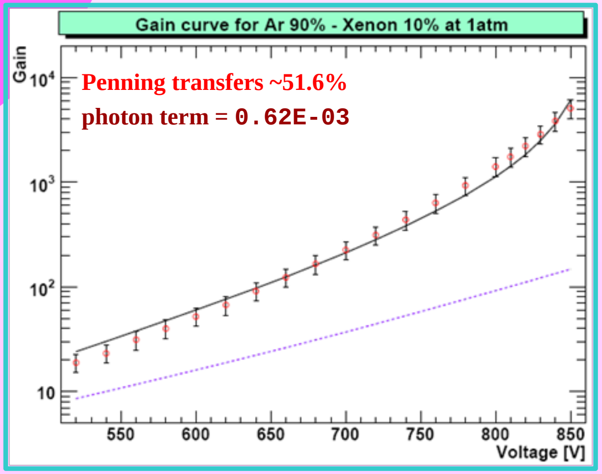
Possible Penning Tranfers:

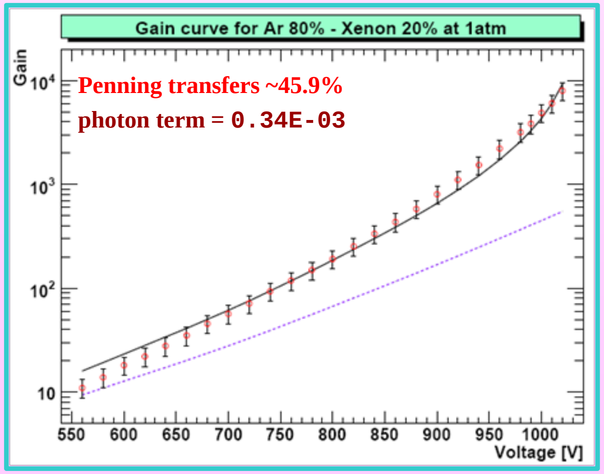
Ar* (P, D level exc.) ⟶ Xe

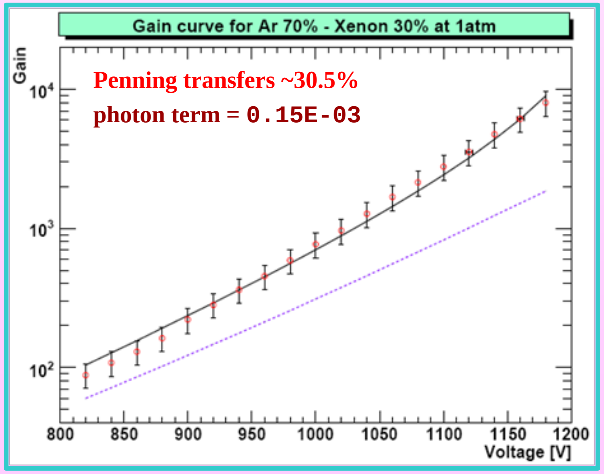
Ar + 5%, 10%, 15%, 20% Xe



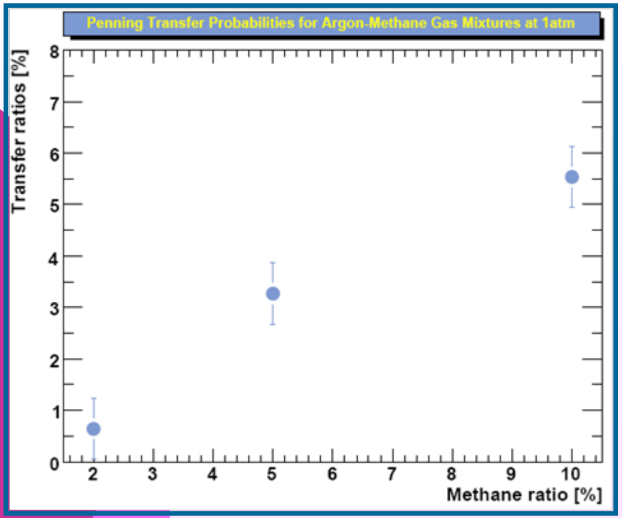


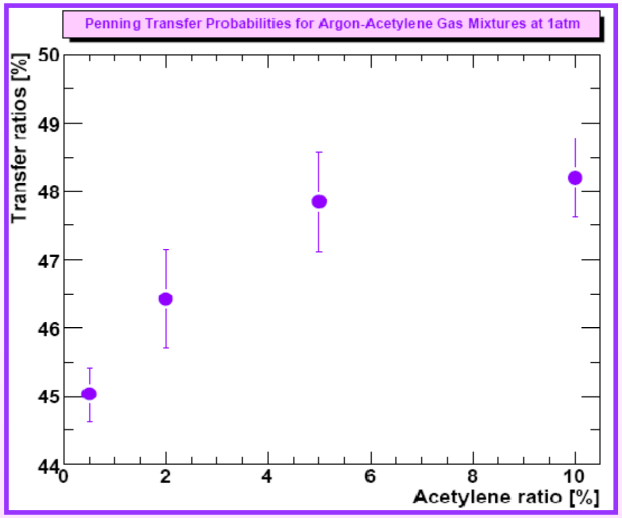


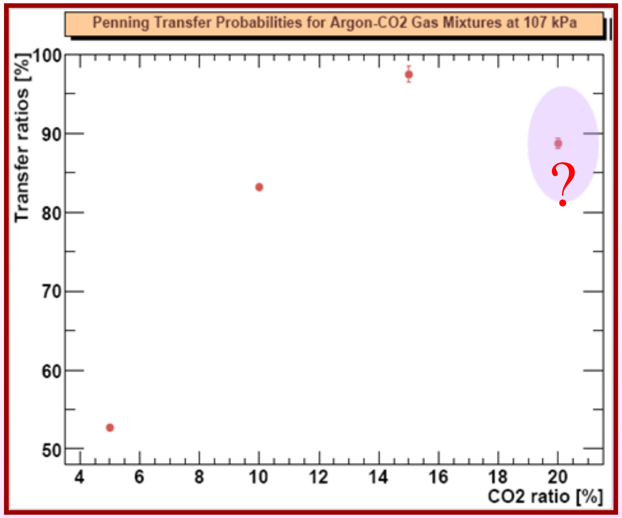




Concentration dependence



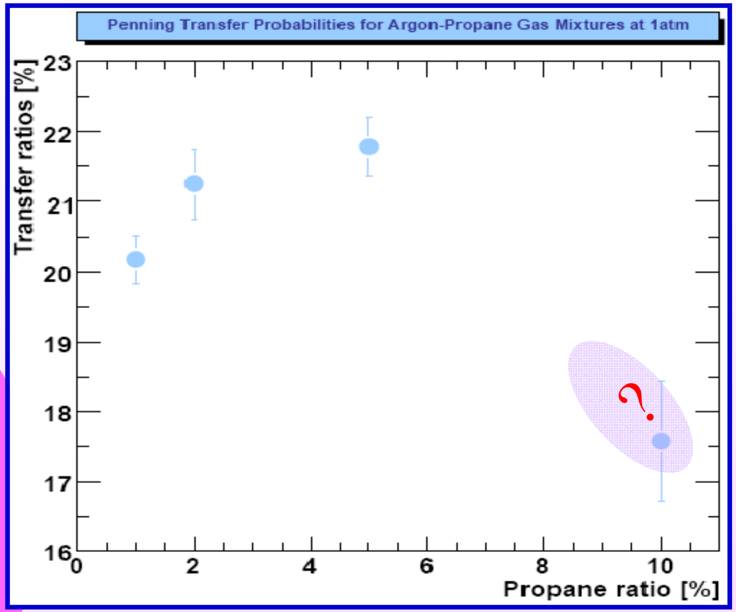


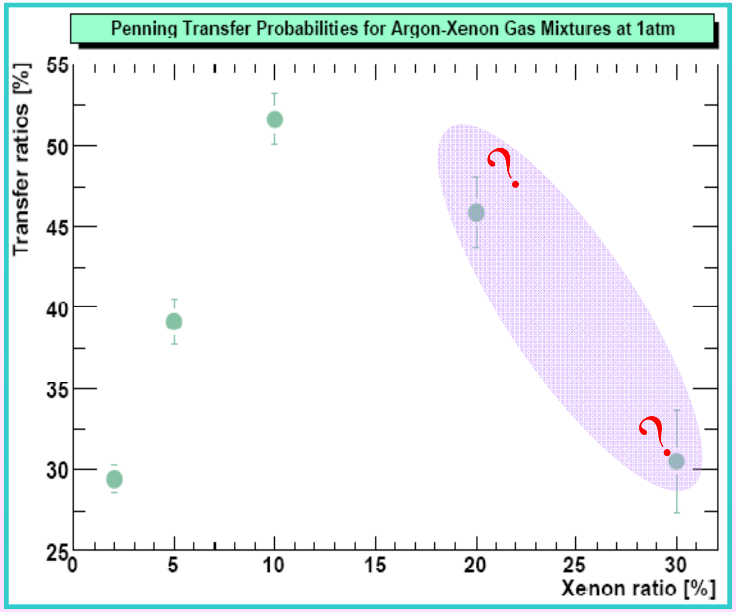


- ➢ Probabilities increase with increasing percentage of the admixture.
- ➢ High probabilities for Acetylene mixtures.
- ➢ The highest probabilities for CO_2 admixtures ?
- ➢ Decrease for 20% CO_2 concentration ?

X sections ?

Concentration dependence (continue)

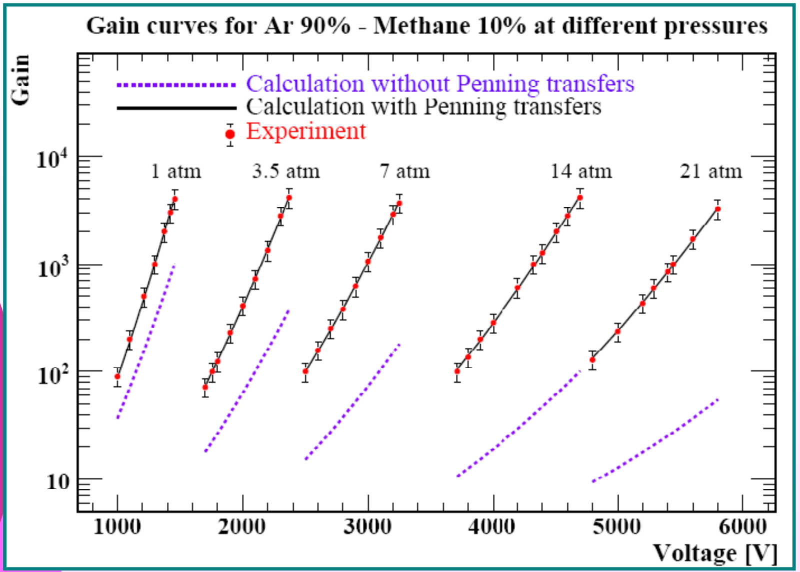


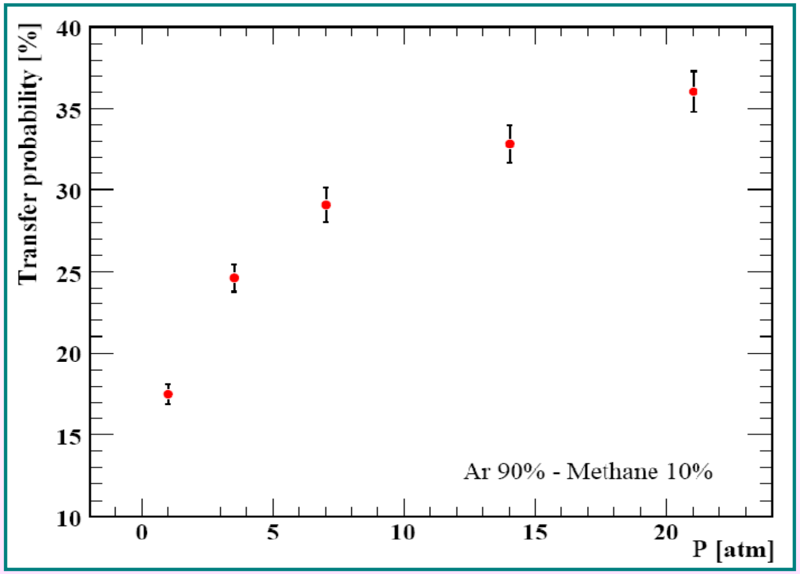


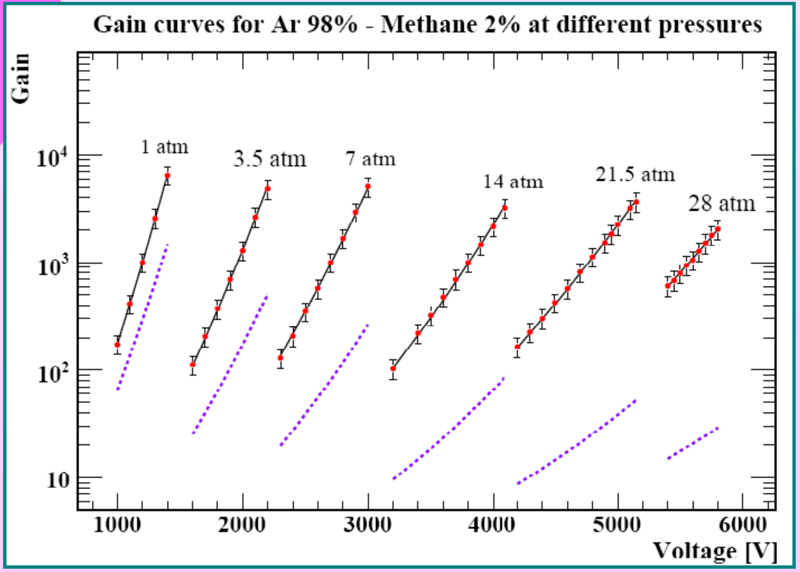
- Decrease for 10% Propane concentration ?
- High probabilities for Xe admixtures ?
- Decrease for 20% and 30% Xe concentrations ?

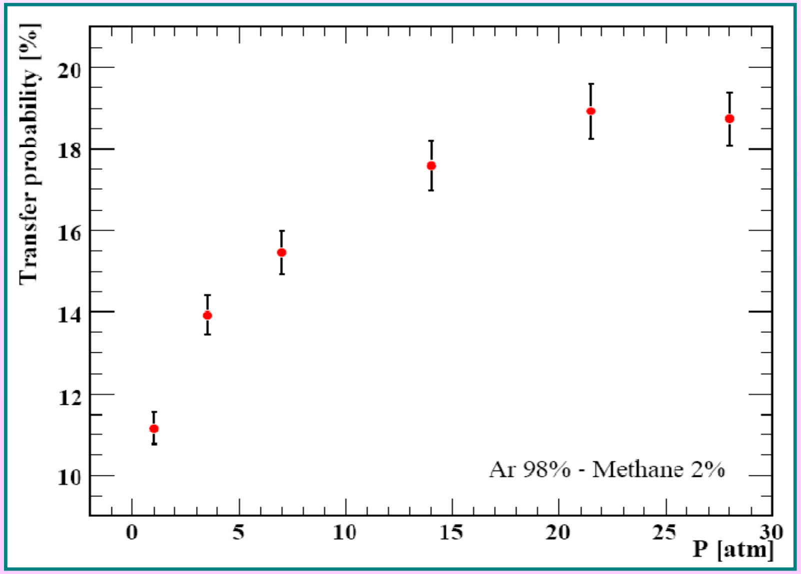
X sections ?

Pressure dependence









Pressure dependence (continue)

- Since the time between collisions decreases by increasing pressure, the number of ionising collisions with excited argon atoms increases. As a consequence, the Penning transfer probabilities increase at higher pressures.

- We assume that the transfer probability is related to the chance that an excited atom (or molecule) meets a recipient before it decays spontaneously in the t_{decay} time.
- We are trying to find correct fit function for pressure dependence.
- We have already calculated mean collision times t_{coll} of argon with investigated admixtures (*from knetic theory*).
- We have also extracted the decay modes and lifetimes for each excited state of argon (*using approximately 40 papers published in this topic*).

Lifetime of the excited states

Levels		Energy	Lifetimes [ns]	
jK	Paschen	[eV]	Experimental	Theoretical
4s (3/2)$_1$	1s$_4$	11.624	8.44[a]	8.60[a]
4s' (1/2)$_1$	1s$_2$	11.828	2.14[a]	2.15[a]
4p (1/2)$_1$	2p$_{10}$	12.907	32.4[b]	32.2[c]
4p (5/2)$_3$	2p$_9$	13.076	25.3[b]	25.2[c]
4p (5/2)$_2$	2p$_8$	13.095	26.8[b]	27.0[c]
4p (3/2)$_1$	2p$_7$	13.153	24.8[b]	25.8[c]
4p (3/2)$_2$	2p$_6$	13.172	24.4[b]	25.3[c]
4p (1/2)$_0$	2p$_5$	13.273	21.6[b]	22.0[c]
4p' (3/2)$_1$	2p$_4$	13.283	26.4[b]	26.0[c]
4p' (3/2)$_2$	2p$_3$	13.302	25.0[b]	25.5[c]
4p' (1/2)$_1$	2p$_2$	13.328	24.2[b]	24.8[c]
4p' (1/2)$_0$	2p$_1$	13.480	19.5[b]	18.5[c]
3d (1/2)$_0$	3d$_6$	13.845	------	54.2[a]
3d (1/2)$_1$	3d$_5$	13.864	94.0[a]	40.8[a]
3d (7/2)$_4$	3d$_4$'	13.979	72.0[d]	52.0[a]
3d (7/2)$_3$	3d$_4$	14.013	55.0[d]	50.8[a]
3d (3/2)$_2$	3d$_3$	13.903	3.48[a]	57.6[a]
3d (3/2)$_1$	3d$_2$	14.153	40.0[d]	9.0[a]
3d (5/2)$_2$	3d$_1$''	14.063	68.0[d]	49.9[a]
3d (5/2)$_3$	3d$_1$'	14.099	54.0[d]	49.0[a]
3d' (5/2)$_2$	3s$_1$''''	14.214	51.9[e]	49.9[a]
3d' (5/2)$_3$	3s$_1$'''	14.236	------	49.7[a]
3d' (3/2)$_2$	3s$_1$''	14.234	49.9[e]	48.3[a]
3d' (3/2)$_1$	3s$_1$'	14.304	53.3[e]	3.36[a]
5s (3/2)$_2$	2s$_5$	14.068	------	42.1[a]
5s (3/2)$_1$	2s$_4$	14.090	17.5[a]	4.74[a]
5s' (1/2)$_0$	2s$_3$	14.241	61.0[d]	43.9[a]
5s' (1/2)$_1$	2s$_2$	14.255	10.1[a]	3.2[a]
5p (1/2)$_1$	3p$_{10}$	14.464	170.0[f]	166.0[f]
5p (5/2)$_3$	3p$_9$	14.499	150.0[f]	122.0[f]
5p (5/2)$_2$	3p$_8$	14.506	165.0[f]	129.0[f]
5p (3/2)$_1$	3p$_7$	14.525	170.0[f]	109.0[f]
5p (3/2)$_2$	3p$_6$	14.529	175.0[f]	192.0[f]
5p (1/2)$_0$	3p$_5$	14.588	95.0[f]	73.0[f]
5p' (3/2)$_1$	3p$_4$	14.681	180.0[f]	127.0[f]
5p' (3/2)$_2$	3p$_3$	14.688	175.0[f]	123.0[f]
5p' (1/2)$_1$	3p$_2$	14.687	170.0[f]	123.0[f]
5p' (1/2)$_0$	3p$_1$	14.738	80.0[f]	83.0[f]
4d (1/2)$_0$	4d$_6$	14.694	120.0[g]	124.0[g]
4d (1/2)$_1$	4d$_5$	14.711	74.0[a]	113.0[a]
4d (7/2)$_4$	4d$_4$'	14.757	226.0[g]	230.0[g]
4d (7/2)$_3$	4d$_4$	14.781	285.0[g]	297.0[g]
4d (3/2)$_2$	4d$_3$	14.743	147.0[g]	384.0[g]
4d (3/2)$_1$	4d$_2$	14.859	200.0[f]	234.0[f]
4d (5/2)$_2$	4d$_1$''	14.809	360.0[f]	348.0[f]
4d (5/2)$_3$	4d$_1$'	14.834	350.0[f]	335.0[f]
4d' (5/2)$_2$	4s$_1$''''	14.955	295.0[f]	275.0[f]
4d' (5/2)$_3$	4s$_1$'''	14.972	310.0[g]	317.0[g]
4d' (3/2)$_2$	4s$_1$''	14.953	223.0[g]	259.0[g]
4d' (3/2)$_1$	4s$_1$'	15.004	71.9[h]	3.78[a]

Lifetime of the excited states (continue)

Levels jK	Levels Paschen	Energy [eV]	Lifetimes [ns] Experimental	Lifetimes [ns] Theoretical
6s $(3/2)_2$	$3s_5$	14.839	72.0[f]	92.0[f]
6s $(3/2)_1$	$3s_4$	14.848	------	5.73[a]
6s' $(1/2)_0$	$3s_3$	15.014	75.0[f]	90.0[f]
6s' $(1/2)_1$	$3s_2$	15.022	------	32.6[a]
4f $(5/2)_{2,3}$	$4Y_{2,3}$	14.907		47.0[a] - 51.0[a]
4f $(7/2)_{1,2}$	$4X_{1,2}$	14.902	------	43.3[a] - 48.3[a]
4f $(9/2)_{4,5}$	$4V_{4,5}$	14.904	------	46.9[a] - 45.4[a]
4f $(7/2)_{3,4}$	$4U_{3,4}$	14.909	------	49.3[a] - 49.6[a]
4f $(5/2)_{2,3}$	$4Z_{2,3}$	15.083	------	46.6[a] - 50.5[a]
4f $(7/2)_{3,4}$	$4W_{3,4}$	15.083	------	46.7[a] - 47.6[a]
6p $(1/2)_1$	$4p_{10}$	15.011	324.0[f]	325.0[f]
6p $(5/2)_3$	$4p_9$	15.023	282.0[i]	276.0[a]
6p $(5/2)_2$	$4p_8$	15.026	266.0[j]	284.0[j]
6p $(3/2)_1$	$4p_7$	15.034	280.0[j]	296.0[j]
6p $(3/2)_2$	$4p_6$	15.036	257.7[i]	257.0[i]
6p $(1/2)_0$	$4p_5$	15.060	171.0[f]	151.0[f]
6p' $(3/2)_1$	$4p_4$	15.202	------	263.0[a]
6p' $(3/2)_2$	$4p_3$	15.205	255.2[j]	256.0[j]
6p' $(1/2)_1$	$4p_2$	15.201	266.7[j]	250.0[j]
6p' $(1/2)_0$	$4p_1$	15.224	190.0[f]	197.0[f]
5d $(1/2)_0$	$5d_6$	15.101	116.0[g]	127.0[g]
5d $(1/2)_1$	$5d_5$	15.118	73.2[h]	111.0[a]
5d $(7/2)_4$	$5d_4'$	15.131	255.0[g]	218.0[g]
5d $(7/2)_3$	$5d_4$	15.146	320.0[g]	337.0[g]
5d $(3/2)_2$	$5d_3$	15.137	205.0[g]	437.0[g]
5d $(3/2)_1$	$5d_2$	15.190	------	2.69
5d $(5/2)_2$	$5d_1''$	15.161	330.0[g]	582.0[g]
5d $(5/2)_3$	$5d_1'$	15.167	475.0[g]	592.0[g]
5d' $(5/2)_2$	$5s_1''''$	15.313	227.0[g]	235.0[g]
5d' $(5/2)_3$	$5s_1'''$	15.319	247.0[g]	275.0[g]
5d' $(3/2)_2$	$5s_1''$	15.296	134.0[g]	146.0[g]
5d' $(3/2)_1$	$5s_1'$	15.351	87.8[h]	0.97[a]
7s $(3/2)_2$	$4s_5$	15.181	133.3[i]	99.3[a]
7s $(3/2)_1$	$4s_4$	15.185	59.7[i]	15.1[a]
7s' $(1/2)_0$	$4s_3$	15.358	------	99.2[a]
7s' $(1/2)_1$	$4s_2$	15.359	38.8[i]	15.7[a]
7p $(3/2)_2$	$5p_6$	15.285	367.2[i]	------
7p $(1/2)_0$	$5p_5$	15.298	309.1[i]	------
6d $(1/2)_0$	$6d_6$	15.308	167.0[g]	162.0[g]
6d $(1/2)_1$	$6d_5$	15.313	281.4[k]	------
6d $(7/2)_4$	$6d_4'$	15.331	297.0[g]	267.0[g]
6d $(7/2)_3$	$6d_4$	15.346	500.0[g]	572.0[g]
6d $(5/2)_3$	$6d_1'$	15.353	295.0[g]	803.0[g]
6d' $(5/2)_2$	$6s_1''''$	15.512	295.0[g]	299.0[g]
6d' (3/2)2	$6s_1''$	15.506	210.0[g]	224.0[g]
8s $(3/2)_2$	$5s_5$		256.0[i]	------
7d $(1/2)_0$	$7d_6$	15.439	116.2[h]	------
7d $(1/2)_1$	$7d_5$	15.443	212.0[k]	------
7d $(7/2)_4$	$7d_4'$	15.450	353.0[g]	363.0[g]
7d $(7/2)_3$	$7d_4$	15.455	309.7[h]	------

Thank you …