5. Low Pressure Discharge Lamps

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5.1 Classification of Gas Discharge Lamps

**Low-pressure gas discharge lamps**
- Pressure = 10 µbar to 10 mbar
- Length = approx. 1 m
- Power = 4 – 58 W (200 W)

**High-pressure gas discharge lamps**
- Pressure = > 1 bar
- Length = approx. 1 cm
- Power = 100 – 2000 W
### 5.1 Classification of Gas Discharge Lamps

<table>
<thead>
<tr>
<th>Mercury</th>
<th>Sodium</th>
<th>Noble gases</th>
<th>Sulphur</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low pressure</td>
<td>High pressure</td>
<td>Low pressure</td>
<td>High pressure</td>
</tr>
<tr>
<td>p &lt; 10 mbar</td>
<td>p &gt; 1 bar</td>
<td>p &gt; 1 bar</td>
<td>p &gt; 1 bar</td>
</tr>
<tr>
<td>Hg/Ar Hg/Ne</td>
<td>Hg/Ar</td>
<td>Na/Ar/Ne</td>
<td>S₂</td>
</tr>
<tr>
<td>185 + 254 nm</td>
<td>Broadband spectrum</td>
<td>589 nm</td>
<td>Broad band spectrum</td>
</tr>
<tr>
<td>Compact fluorescent lamps or Fluorescent lamps</td>
<td>Line emitters NaX / TIX / InX, X = I, Br</td>
<td>High pressure Na/Hg/Xe</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Multi line emitters NaX / TIX / LnX₃ (Ln = Dy, Ho, Tm, Sc) SnX₂</td>
<td>Sodium vapour lamps</td>
<td>Xe/Ne</td>
</tr>
<tr>
<td></td>
<td>Metal halide lamps</td>
<td></td>
<td>147 + 172 nm Plasma displays</td>
</tr>
</tbody>
</table>

- **Mercury**: Line emitters NaX / TIX / InX, X = I, Br, Multi line emitters NaX / TIX / LnX₃ (Ln = Dy, Ho, Tm, Sc) SnX₂, Metal halide lamps
- **Sodium**: Na/Ar/Ne, 589 nm, High pressure Na/Hg/Xe
- **Noble gases**: Ne, 74 nm, Medium pressure Na/Hg/Xe
- **Sulphur**: S₂, Broad band spectrum

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5.2 Historical Development

1852  Stokes: Monitoring of the phenomena “fluorescence”
1938  General electric: First fluorescent lamp, phosphor = (Zn,Be)$_2$SiO$_4$:Mn (40 lm/W)
1942  Fluorescent lamps with halophosphate: 60 lm/W
1971  Trichromatic fluorescent lamps: 100 lm/W
5.3 Principle of Fluorescent Lamps

Gas discharge $\rightarrow$ UV radiation $\rightarrow$ Visible light

- Cleaning
- Disinfection
- Lighting
5.3 Principle of Fluorescent Lamps

Without phosphor

With phosphor
5.4 Low-Pressure Mercury Discharge

In gas discharge lamps, light is generated primarily by an electrically excited plasma.

Definition of a plasma
Mixture of electrons, ions and neutral particles in different excited states and with strong interaction with each other.

a) Isothermal plasma: All particles are in thermodynamic equilibrium
(high temperature plasmas: stars)

b) Non-isothermal plasma: Only electrons are in thermodynamic equilibrium
(electrically generated plasmas: gas discharge lamps)

In gas discharge lamps, gas atoms are in fact not ionized.

A significant ionization starts to occur at temperatures above 4000 K.
5.4 Low-Pressure Mercury Discharge

Spectrum of a gas discharge is caused by several physical processes

1. Line emission (fluorescence)
   - $\text{Hg}^* \rightarrow \text{Hg} + h\nu$
   - $\text{Ar}^* \rightarrow \text{Ar} + h\nu$
   - $\text{Na}^* \rightarrow \text{Na} + h\nu$

2. Recombination radiation
   - $\text{Hg}^+ + e^- \rightarrow \text{Hg} + h\nu$

3. Bremsstrahlung
   - Thermalization of electrons

Additional contributions
- Excimer radiation
- Phosphor emission
- Emission of LnX$_3$-filling
5.4 Low-Pressure Mercury Discharge

Energy level diagram of Hg-atom and emission spectrum of a low pressure mercury gas discharge

\[
\begin{align*}
[Xe]\text{4f}^{14}\text{5d}^{10}\text{6s}^2 & \rightarrow \ [Xe]\text{4f}^{14}\text{5d}^{10}\text{6s}^1\text{6p}^1 \\
\text{Ground state term: } ^1S_0 \text{ (all shells filled)} \\
\Rightarrow \text{Hg discharge appears bluish-white}
\end{align*}
\]
5.4 Low-Pressure Mercury Discharge

Processes in the gas discharge

1. Thermal emission of electrons
   Cathode → e⁻

2. Elastic scattering of Hg and Ar (buffer gas)
   e⁻ + Hg → e⁻ + Hg
   e⁻ + Ar → e⁻ + Ar

3. Excitation of Hg atoms
   e⁻ + Hg → e⁻ + Hg* (³P₁)
   e⁻ + Hg → e⁻ + Hg* (¹P₁)

4. Ionization of Hg atoms
   e⁻ + Hg → 2 e⁻ + Hg⁺

5. Relaxation of excited Hg atoms
   Hg*(³P₁, ¹P₁, ... ) → Hg + hν_{UV}

In a low pressure mercury gas discharge about 70% of electrical input power is converted into UV radiation
5.5 Energy Balance

Loss processes in fluorescent lamps

Work function + plasma efficiency

Stokes shift + quantum yield

<table>
<thead>
<tr>
<th></th>
<th>Electrical input power (100%)</th>
<th>UV-radiation (70%)</th>
<th>Visible radiation (30%)</th>
<th>Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work function + plasma efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stokes shift + quantum yield</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ε_{dis} = Plasma efficiency</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Quantum deficit (Stokes-Shift) = \[\lambda_{\text{Plasma}}/\lambda_{\text{Phosphor}}\] = 0.46

Quantum yield = \(N_{\text{emitted photons}}/N_{\text{absorbed photons}}\) \(\sim\) 0.9

Linear Fluorescent Lamps (TL) \(\varepsilon_{\text{dis}} = 70\% \implies \varepsilon = 30\%\) (100 lm/W)

Compact Fluorescent Lamps (CFL) \(\varepsilon_{\text{dis}} = 40\% \implies \varepsilon = 18\%\) (60 lm/W)
## 5.6 Typical Dimensions

### Fluorescent tubes

<table>
<thead>
<tr>
<th>Output</th>
<th>Length</th>
<th>Diameter</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 W</td>
<td>0.6 m</td>
<td>T8</td>
<td>T8 = 8/8 inch = 2.54 cm</td>
</tr>
<tr>
<td>36 W</td>
<td>1.2 m</td>
<td>T8</td>
<td></td>
</tr>
<tr>
<td>58 W</td>
<td>1.5 m</td>
<td>T8</td>
<td></td>
</tr>
<tr>
<td>4 W</td>
<td>0.14 m</td>
<td>T5</td>
<td>T5 = 5/8 inch = 1.59 cm</td>
</tr>
<tr>
<td>6 W</td>
<td>0.21 m</td>
<td>T5</td>
<td></td>
</tr>
<tr>
<td>8 W</td>
<td>0.30 m</td>
<td>T5</td>
<td></td>
</tr>
<tr>
<td>13 W</td>
<td>0.50 m</td>
<td>T5</td>
<td></td>
</tr>
</tbody>
</table>

T12 → T8 → T5 → T4 → T3 → T1 (0.32 cm): Increasing wall load

Today: LED Retrofit lamps

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5.7 Components of Fluorescent Lamps

Functional parts

1. Ballast or control gear and starter
2. Electrodes and emitter
3. Glass
4. Coating = pre-coating + phosphor
5. Gas filling

Diagram:
- Ballast or control gear (1)
- Electrode (2)
- Coating (4)
- Glass (3)
- Gas filling (5)
Why is a ballast required?

Discharge lamps have a negative current-voltage characteristic

\[ U = R \cdot I \quad \Rightarrow \quad U = \frac{I}{S} \]

Increases more than linearly with \( n_e \)

**Incandescent lamps**

**Discharge lamps**
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5.8 Ballast

36 W FL: $U = 100 \text{ V}$, $I = 0.36 \text{ A}$

$R$: $U_R = 130 \text{ V}$, $I_R = 0.36 \text{ A}$ \Rightarrow $R = 360 \Omega$

$\Rightarrow 130/230 = 56\%$ of power output is consumed in $R$

$\Rightarrow \eta = 100 \text{ lm/W} \times 44\% = 44 \text{ lm/W}$

Solution: "ballasted" with a coil (inductance) or a capacitor (capacitance)

$\Rightarrow$ in $L$ and $C$ are the current and voltage phase shifted by $90^\circ$

$\Rightarrow$ no power output is consumed
5.9 Electrodes and Emitters

Electrodes release electrons into the gas phase by thermal emission

Material: Tungsten (emission of electrons from about 2000 °C)

Typical design: Double-coil
Thermal thermionic emission of electrodes is described by the Richardson law

\[ I = \text{Area} \cdot A \cdot T^2 \cdot e^{-\frac{W_A}{kT}} \]

- \( A = \text{Richardson constant} = 60 \, \text{A/cm}^2\text{K}^2 \)
- \( W_A = \text{Work function (4.54 eV for tungsten)} \)
- \( kT = \text{Thermal energy [J]} \)
- \( k = \text{Boltzmann's constant} = 1.38 \cdot 10^{-23} \, \text{J/K} \)

Probability that an electron leaves the surface is

\[ e^{-\frac{W_A}{kT}} \]
Electrodes made out of tungsten $\Rightarrow$ Richardson: $I = 0.5\,\text{A}$  
$\Rightarrow T_W = 3100\,\text{K}$  
$\Rightarrow$ Energy costs  
$\Rightarrow$ Efficiency decreases

Solution
Electrode is coated with an emitter
Emitter = Material with low work function

<table>
<thead>
<tr>
<th>Material</th>
<th>$W_A,[\text{eV}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>4.5</td>
</tr>
<tr>
<td>Ba</td>
<td>2.5</td>
</tr>
<tr>
<td>Sr</td>
<td>2.4</td>
</tr>
<tr>
<td>Ca</td>
<td>2.8</td>
</tr>
<tr>
<td>BaO</td>
<td>1.0 – 1.7</td>
</tr>
<tr>
<td>SrO</td>
<td>1.3 – 1.6</td>
</tr>
<tr>
<td>CaO</td>
<td>1.6 – 1.9</td>
</tr>
<tr>
<td>$Y_2O_3$</td>
<td>2.0 – 3.9</td>
</tr>
</tbody>
</table>

Arc operates at about 1 mm$^2$ area

I = 0.5 A even at $T_{Ba} = 1350\,\text{K}$
5.9 Electrodes and Emitters

Used emitter materials

- $\text{Y}_2\text{O}_3$ High pressure sodium lamps
- $\text{BaO}/\text{SrO}/\text{CaO}$ Na/Hg-low pressure lamps

Application as stable carbonates "triple mix"

1. Dip coating of the electrode with a suspension of the "triple mix"

2. Activation in the lamp: $\text{MeCO}_3 \rightarrow \text{MeO} + \text{CO}_2 \uparrow$ (Me = Ca, Sr, Ba)

3. Operation of the lamp: $\text{W} + 6 \text{BaO} \rightarrow \text{Ba}_3\text{WO}_6 + 3 \text{Ba}$ (emitter)
# 5.10 Lamp Glass

## General requirements

- Low cost (< 1 ct/lamp)
- High transparency
- Radiation stability (lower solarisation)
- Thermal stability

## Composition of typical glasses for lamps

<table>
<thead>
<tr>
<th>Komposition [%]</th>
<th>Natriumsilikat</th>
<th>Bleisilikat</th>
<th>Borsilikat</th>
<th>Aluminosilikat</th>
<th>Aluminoborat</th>
<th>Quarz</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>73</td>
<td>64</td>
<td>75</td>
<td>63</td>
<td>8</td>
<td>100</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>16</td>
<td>8</td>
<td>4</td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K$_2$O</td>
<td>1</td>
<td>6</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>5</td>
<td>6</td>
<td>9</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MgO</td>
<td>4</td>
<td></td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>16</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>PbO</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B$_2$O$_3$</td>
<td></td>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td>48</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Anwendung in</th>
<th>Glühlampen</th>
<th>Glühlampen</th>
<th>Hg-Hoch-</th>
<th>Halogenlampen</th>
<th>Na-Nieder-</th>
<th>UV-C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fluoreszenzlampen</td>
<td>Fluoreszenzlampen</td>
<td>Drucklampen</td>
<td></td>
<td>Drucklampen</td>
<td>Lampen</td>
</tr>
</tbody>
</table>
### 5.10 Lamp Glass

**Transmission of lamp glasses**

<table>
<thead>
<tr>
<th>Lamp application</th>
<th>Absorption edge [nm]</th>
<th>Type of glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lighting</td>
<td>320</td>
<td>Sodium silicate glass</td>
</tr>
<tr>
<td>Tanning beds</td>
<td>300</td>
<td>Modified sodium silicate glass</td>
</tr>
<tr>
<td>Disinfection</td>
<td>220</td>
<td>Modified sodium silicate glass</td>
</tr>
<tr>
<td>Purification</td>
<td>170</td>
<td>Quartz (synthetic)</td>
</tr>
</tbody>
</table>

![Graph showing transmission of lamp glasses](graph.png)

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### 5.11 Coating

#### Basic structure

- Phosphor coating (phosphor + filling)
- Pre-coating (Al₂O₃, Y₂O₃, MgO, ....)

#### Schematic layer build-up

<table>
<thead>
<tr>
<th>Dispersion medium</th>
<th>Butylacetat</th>
<th>Demineralised water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binder</td>
<td>Nitrocellulose</td>
<td>Polyethylene oxide</td>
</tr>
<tr>
<td>Phosphor</td>
<td>Halophosphate</td>
<td>Halophosphates</td>
</tr>
<tr>
<td></td>
<td>Color 80 phosphors</td>
<td>Color 80 phosphors</td>
</tr>
<tr>
<td></td>
<td>Color 90 phosphors</td>
<td>Color 90 phosphors</td>
</tr>
<tr>
<td></td>
<td>UV-phosphors</td>
<td></td>
</tr>
<tr>
<td>Adhesive agent</td>
<td>Alon-c (Al₂O₃)</td>
<td>Ca₂P₂O₇ or Sr₂P₂O₇</td>
</tr>
<tr>
<td>Dispersion agent</td>
<td>2-Methoxy-1-propanol</td>
<td>Polyacrylic acid</td>
</tr>
</tbody>
</table>
5.11 Coating

With fluorescent halophosphate (apatite)

\[ \text{Ca}_5\text{(PO}_4\text{)}_3\text{(F,Cl)}:\text{Sb}^{3+},\text{Mn}^{2+} \]

\[ (\text{Sb}^{3+}) + h\nu_{254} \rightarrow (\text{Sb}^{3+})^* \]

\[ (\text{Sb}^{3+})^* \rightarrow (\text{Sb}^{3+}) + h\nu_{480} \]

\[ (\text{Sb}^{3+})^* + (\text{Mn}^{2+}) \rightarrow (\text{Sb}^{3+}) + (\text{Mn}^{2+})^* \]

\[ (\text{Mn}^{2+})^* \rightarrow (\text{Mn}^{2+}) + h\nu_{580} \]

Sb/Mn mass ratio determines color temperature

Light yield = 75 - 80 lm/W\text{el}

Colour rendering index CRI = 60
5.11 Coating

With a trichromatic blend of phosphors (red-green-blue RGB)

Required positions of the emission bands

Blue  440 - 460 nm  Eu\(^{2+}\)

Green  540 - 560 nm  Tb\(^{3+}\)

Red  590 - 630 nm  Eu\(^{3+}\)

Light yield = 100 lm/W\(_{el}\)
Color rendering index CRI = 80 - 85
Optimum at about
- Light yield 100 lm/W_{el}
- CRI = 80 - 85 (⇒ Color 80 lamps)
5.11 Coating

Emission spectrum of a trichromatic lamp

\[ \text{LaPO}_4: \text{Ce}^{3+}\text{Tb}^{3+} \]

\[ \text{BaMgAl}_{10}\text{O}_{17}: \text{Eu}^{2+} \]

\[ \text{Y}_2\text{O}_3: \text{Eu}^{3+} \]

\[ \text{Prad} = 36 \text{ W} \]

\[ \text{Prad} / \text{Prad,vis} \approx 60 \% \]

\[ \text{Prad,vis} / \text{Pel.} \approx 30 \% \]
5.11 Coating

Color points of trichromatic lamps

Color temperature
2700 - 6500 K

Only green and red phosphor
2700 K

RGB phosphor mixture
2700 - 6500 K depending on the mixing ratio

Color point
Is adjusted so that it lies close to the black body-line
5.11 Coating

### Lanthanide ions
- Ce\(^{3+}\)
- LaPO\(_4\):Ce
- YPO\(_4\):Ce
- Eu\(^{2+}\)
- Sr\(_5\)(PO\(_4\))\(_3\):(F,Cl):Eu
- BaMgAl\(_{10}\)O\(_{17}\):Eu
- Tb\(^{3+}\)
- LaPO\(_4\):Ce,Tb
- CeMgAl\(_{11}\)O\(_{19}\):Tb
- LaMgB\(_5\)O\(_{10}\):Ce,Tb
- Eu\(^{3+}\)
- Y\(_2\)O\(_3\):Eu
- (Y,Gd)(V,P)O\(_4\):Eu

### s\(^2\)- or TM-ions
- Pb\(^{2+}\)
- Sr\(_2\)MgSi\(_2\)O\(_7\):Pb
- BaSi\(_2\)O\(_5\):Pb
- Sb\(^{3+}\)
- Ca\(_5\)(PO\(_4\))\(_3\):(F,Cl):Sb
- Mn\(^{2+}\)
- BaMgAl\(_{10}\)O\(_{17}\):Eu,Mn
- Zn\(_2\)SiO\(_4\):Mn
- Ca\(_5\)(PO\(_4\))\(_3\):(F,Cl):Sb,Mn
- LaMgB\(_5\)O\(_{10}\):Ce,Tb,Mn
- Mn\(^{4+}\)
- Mg\(_4\)GeO\(_{5.5}\)F:Mn
5.11 Coating

Color rendering (trichromatic phosphor blends)
• Fairly good color rendering  \( R_a = 80 – 85 \)
• Lack of radiation in the
  – cyan  \( 500 – 535 \) nm
  – yellow  \( 560 – 580 \) nm
  – deep red  \( > 610 \) nm

Consequences
• Additional broad band phosphors
  – \( \text{Sr}_4\text{Al}_{14}\text{O}_{25}:\text{Eu} \)
  – \( \text{Ca}_5(\text{PO}_4)_3(\text{F,Cl}):\text{Sb},\text{Mn} \)
• Modification of applied trichromatic phosphors
  – \( \text{BaMgAl}_{10}\text{O}_{17}:\text{Eu} \rightarrow \text{BaMgAl}_{10}\text{O}_{17}:\text{Eu},\text{Mn} \)
  – \( \text{GdMgB}_5\text{O}_{10}:\text{Gd},\text{Tb} \rightarrow \text{GdMgB}_5\text{O}_{10}:\text{Ce},\text{Tb},\text{Mn} \)
  \( \rightarrow R_a \sim 88 – 90, \) but luminous efficiency  \( \sim 60 – 80 \) lm/W

<table>
<thead>
<tr>
<th>Typical blend (Osram Patent EP1306885)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Sr}<em>4\text{Al}</em>{14}\text{O}_{25}:\text{Eu} )</td>
<td>28.5 wt-%</td>
</tr>
<tr>
<td>( (\text{Ce,Gd})(\text{Zn,Mg})\text{B}<em>5\text{O}</em>{10}:\text{Mn} )</td>
<td>28.5 wt-%</td>
</tr>
<tr>
<td>( \text{Ca}_5(\text{PO}_4)_3(\text{F,Cl}):\text{Sb},\text{Mn} )</td>
<td>26.9 wt-%</td>
</tr>
<tr>
<td>( \text{BaMgAl}<em>{10}\text{O}</em>{17}:\text{Eu} )</td>
<td>6.1 wt-%</td>
</tr>
<tr>
<td>( \text{CeMgAl}<em>{11}\text{O}</em>{19}:\text{Tb} )</td>
<td>10.0 wt-%</td>
</tr>
</tbody>
</table>

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5.11 Coating

Fluorescent lamps with high color rendering

Application of $\text{BaMgAl}_{10}\text{O}_{17}:\text{Eu},\text{Mn}$

Emission spectrum of a mixture of $\text{BaMgAl}_{10}\text{O}_{17}:\text{Eu},\text{Mn} + \text{LaPO}_{4}:\text{Ce},\text{Tb} + \text{Y}_2\text{O}_3:\text{Eu}$ at 254 nm excitation

Measured emission spectra of fluorescent lamps with a mixture of $\text{BaMgAl}_{10}\text{O}_{17}:\text{Eu},\text{Mn} + \text{Y}_3\text{Al}_5\text{O}_{12}:\text{Ce} + \text{YVO}_4:\text{Eu}$ (Al$_2$O$_3$ coated)

$\text{Ra} \sim 88$

$\text{Ra} > 90$
5.12 Hg-Take up

The low-pressure mercury discharge requires for optimum operation 50 µg Hg

Standard dosage: 10 - 20 mg/Lamp

Reason: Hg consumption by lamp components $\rightarrow$ Hg take-up

<table>
<thead>
<tr>
<th>Lamp component</th>
<th>Hg consumption in 10000 h (4 ft TL Lamp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>5 mg</td>
</tr>
<tr>
<td>Phosphor</td>
<td>0.1 - 2.0 mg</td>
</tr>
<tr>
<td>Electrodes</td>
<td>0.1 - 1.0 mg</td>
</tr>
</tbody>
</table>

$\Rightarrow$ Hg higher doses to compensate Hg consumption during the specified life time
5.12 Hg-Take up

Hg adsorption by glass and phosphor leads to the graying of the phosphor and to reduction of the discharge efficiency.

<table>
<thead>
<tr>
<th>Material</th>
<th>IEP [pH]</th>
</tr>
</thead>
<tbody>
<tr>
<td>WO$_3$</td>
<td>2.0</td>
</tr>
<tr>
<td>SiO$_2$/Glass</td>
<td>3.0</td>
</tr>
<tr>
<td>BaSi$_2$O$_5$</td>
<td>3.0</td>
</tr>
<tr>
<td>TiO$_2$</td>
<td>5.6</td>
</tr>
<tr>
<td>ZrO$_2$</td>
<td>6.0</td>
</tr>
<tr>
<td>LaPO$_4$</td>
<td>7.8</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>9.0</td>
</tr>
<tr>
<td>Y$_2$O$_3$</td>
<td>9.0</td>
</tr>
<tr>
<td>ZnO</td>
<td>9.4</td>
</tr>
<tr>
<td>Yb$_2$O$_3$</td>
<td>9.7</td>
</tr>
<tr>
<td>La$_2$O$_3$</td>
<td>10.4</td>
</tr>
<tr>
<td>MgO</td>
<td>11.0</td>
</tr>
</tbody>
</table>

Hg/Hg$^+$-take up decreases with increasing electron density of the anions (alkalinity), i.e. with the increase in reactivity toward electrophilic agents, such as CO$_2$, H$^+$, Hg$^+$.
5.12 Hg-Take up

Measures to reduce Hg-consumption

- Particle Coating
- Glass Coating

With $\text{Y}_2\text{O}_3$ or $\text{Al}_2\text{O}_3$ (low Hg-take up)

3 mg Hg/lamp with $\text{Y}_2\text{O}_3$-glass coating
Compact fluorescent Lamps, also called energy saving lamps, are fluorescent tubes consisting of several (bent) tubes with an integrated ballast.

**Trends**
- Miniaturization
- Incandescent lamp form (outer envelope with a scattering layer)

„incandescent look-a-like“
5.14 Inductively Driven Lamps

QL (Philips), Endura (Osram) lamps have an extremely long service life due to the lack of internal electrodes (light production as well as in conventional fluorescent lamps).
5.14 Inductively Driven Lamps

Construction of a QL-lamp

- Vessel filled with Hg & no internal electrodes
- HF generator with 2.65 MHz
- Power coupler
- Coil

Incoherent Light Sources
Prof. Dr. T. Jüstel

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Energy in-coupling in a QL-lamp

Coil
Alternating electric field $\Rightarrow$ alternating magnetic field (H)
Alternating magnetic field (H) $\Rightarrow$ alternating electric field (E)
Electrons are accelerated in this field E

HF - generator 2.65 MHz
5.15 Low Pressure Sodium Gas Discharge Lamps

Energy level diagram of the Na atom

„Yellow Na-D lines“
[Ne]3p¹ – [Ne]3s¹
Interconfiguration transitions

Na-discharge lines at 589.0 nm, 589.6 nm, 781.0 nm, 818.3 nm
General construction

- Filling element Na with operating pressure of 1 Pa
- Buffer gas: Argon or Krypton
- No phosphor
- Inner and outer glass envelope (bulb)

High efficiency ~ 200 lm/W
but poor light quality $R_a = -50$

Outer bulb with heat-reflective coating ($\rightarrow$ SnO$_2$)