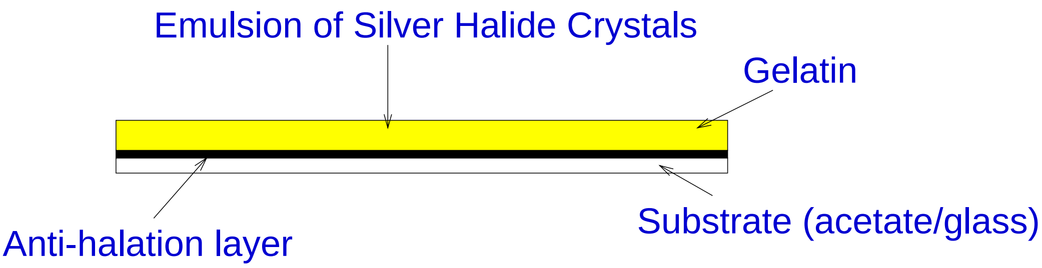
Topic 7: Photographic Process

Aim: To cover the basics of the photographic process, and the properties of photographic material.

Contents:

- Basics of Photographic Process
- Exposure and Transmittance
- Hurter and Driffield Curve
- Characterisation of Photographic Process
- Two stage process
- Transmittance in coherent light.

Structure of Photographic Material



Grain: Emulsion of "Grains" of Silver Halide in Gelatin base.

Grain	$50 \rightarrow 500$ nm $(\lambda/10 \rightarrow \lambda/2)$
Gelatin	$3 \rightarrow 15\ \mu$m thick

Each "grain" contains $10^{11} \rightarrow 10^{12}$ ions, so large on atomic scale.

Silver Halide: Typically mixture of Silver Bromide, Silver Iodide and other Silver salts.

Substrate: Usually acetate or polyester. Glass use when flat stable material needed, (in holography and spectroscopy).

Anti-halation layer: Light blocking layer to prevent internal reflections from substrate.

Full details of photographic process is difficult chemistry, just supply an overview.

Basic Process

Expose to Light

1. Quantum(s) of light free electron(s) in lattice.
2. Electron captured by silver ion (interstitial ion)
3. Migration of silver ions to neutralise local charge
4. Deformation of lattice allows migrated silver ions to form form "speck" of silver in the grain.
5. "Specks" of silver known as **Latent Image**.

Note:

- "Specks" much smaller than the grain, typically 50 to 100 silver atoms.
- Latent Image strength given by number of "specks" so proportional to incident number of photons (intensity)
- Formation of one latent image take about 10^{-4}s (limits film speed).
- In practice, need about 50 photons absorbed by a single grain to form Latent Image.

This process results in the Latent Image recording the incident intensity pattern.

Development

Want to “develop” grains of silver halide exposed to light into solid (opaque) silver.

Two basic processes, **Chemical** and **Physical**.

Chemical Development:
Treat film with weak reducing agent,

1. Add electrons to silver halide that liberates silver.
2. Liberated silver “binds” to latent image specks.
3. Grains with strong latent image “develop” first.

Process is highly temperature dependent, and slow (many minutes). (complex chemical process).

Physical Development:
Basically same principle, but deposited silver mostly comes from silver salts in the developer rather than the silver salts in the film. (very little used due to cost of developer.)

Fixing

Remove remaining silver halide with stronger reducing agent. Typically also contains agents to harden the gelatin to prevent mechanical damage.

Exposure and Transmittance

Define: *Exposure* as Energy per Unit Area incident.
For incident intensity of $g(x,y)$ for time τ:

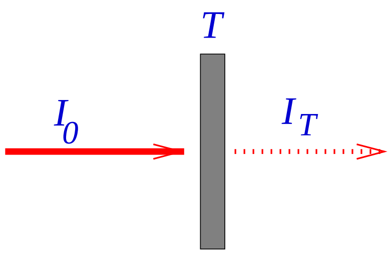
$$E(x,y) = g(x,y)\tau$$

We will typically imply (x,y) dependence, and write

$$E = g\tau$$

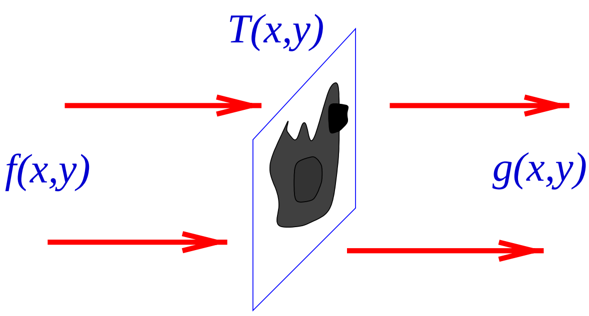
Define: *Intensity Transmittance* at a point (x,y) as

$$T = \frac{\text{Transmitted intensity at } (x,y)}{\text{Incident intensity at } (x,y)}$$



$$T = \frac{I_T}{I_0} \quad \text{so} \quad 0 \leq T \leq 1$$

So in two dimensions we have



$$g(x,y) = f(x,y)\,T(x,y) \quad \text{with} \quad g(x,y) \leq f(x,y)$$

Exposure to Transmittance

Hurter and Driffield showed that

$$\log_{10}\left(\frac{1}{T}\right) \propto \text{Mass of metallic silver}$$

Define: *Optical Density* D as mass of metallic silver per unit area, so:

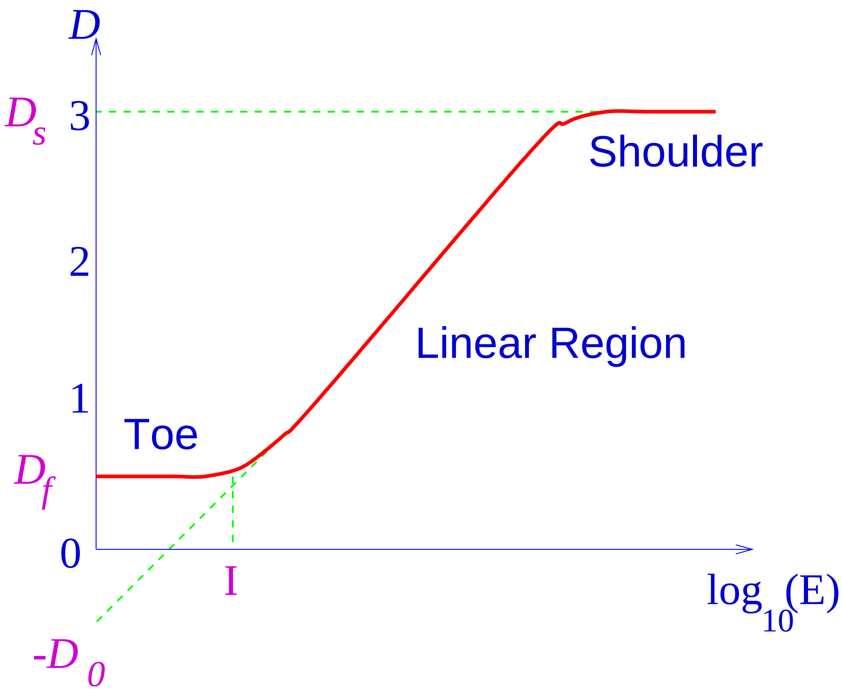
$$D = \log_{10}\left(\frac{1}{T}\right) = -\log_{10}(T)$$

The film characteristics are then experimentally measured as plot of D against E.

Note: Each film has a different characteristic plot. The shape of this plot can also be altered by different types of developer and by changing the development time.

Most manufactured supply technical information on request.

Hurter and Driffield Curve



1. **Low Exposure:** Optical Density not dependent on E. Constant "*Fog Level*" D_f. (Typically $D_f \approx 0.3$)
2. **Medium Exposure:** Linear region where $D \propto \log_{10}(E)$ (Useful region).
3. **High Exposure:** Saturation (all grains developed into silver). Typically $D_s \approx 3.0$ (0.01% transmittance)

Dynamic range of the file is

$$\Delta D = D_s - D_f \approx 2.5 \quad \text{typical film}$$

Film Speed

Film Speed: Measure of D for given Exposure E.

Holographic materials measured in $\mu J \mathrm{cm}^{-2}$, to give a good holographic exposure.

Photographic material "subjective" speed measure when developed in standard developer. Two typical measures:

ASA	Linear with E
DIN	Linear with I (log of exposure)

Typical Film Speeds:

ASA	Type
5	Lithographic film
25	Very slow portrait film
100	Normal b/w or colour film
400	Fast b/w or colour
1000	Fastest normal film
$>$ 1000	Special processing

Used as a guide only: (eg: 400 ASA film requires 1/4 Exposure of 100 ASA). Difficult to get quantative measure.

(See tutorial)

Always get trade-off

Slow speed	Small Grains	High Resolution
High speed	Large Grains	Low Resolution

Linear Region

In linear region we have

$$D = \gamma \log_{10}(E) - D_0$$

where γ is the gradient (Called Film Gamma).

We have that

$$D = -\log_{10}(T) \quad \& \quad E = g\tau$$

so that the intensity transmittance

$$T = 10^{D_0} E^{-\gamma} = 10^{D_0} (g\tau)^{-\gamma}$$

Relation between Exposure E and intensity transmittance T is **NON-LINEAR**.

Key Result

Low Contrast: $\gamma \approx 1$
High speed Black/White file, (HP-5, or Tri-X). *Small* changes in Optical Density with *Large* change in exposure. Films normally *Fast*.

High Contrast: $\gamma \approx 2 \to 3$
Lithogrphic copy film, very *Large* changes in Optical Density with *Small* changes in exposure. Output often binary (black or white). Films noramlly *Slow*.

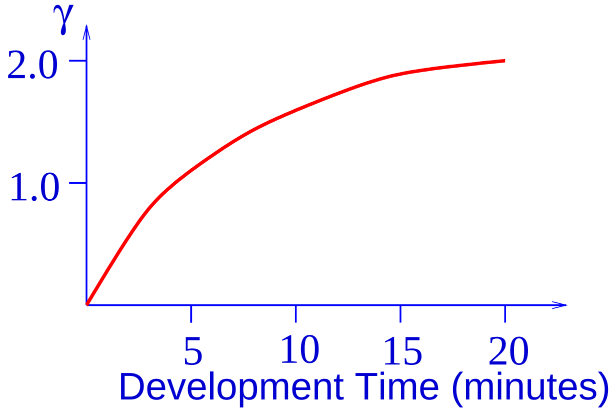
Variation of γ

For film able to modify γ by changing exposure and development conditions.

Increase Gamma: Low exposure plus long/hot development. Weak latent image, only brightest point developed to full darkness, high contrast.

Decrease Gamma: High exposure plus short/cold development. Strong latent image. Latent image only partially developed, low contrast.

For a typical B/W white film (HP-5), we get



so will careful development we can select the γ required.

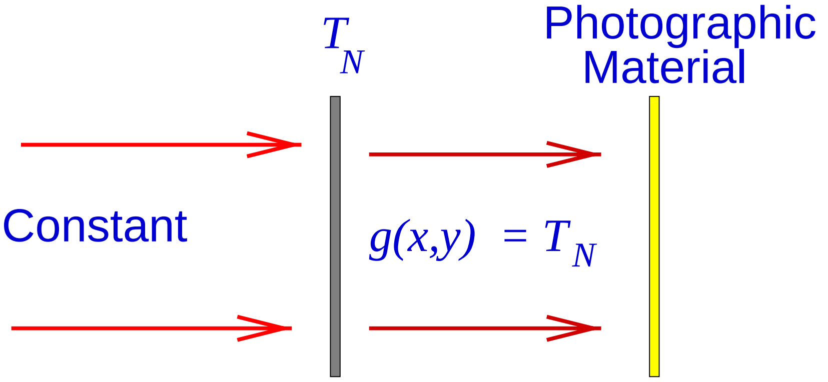
Two Stage Process

Consider two stage photographic process.

1) Form Negative
Incident intensity of $f(x,y)$ for time τ_N with γ_N. *Negative* with

$$T_N = K_N(f\tau_N)^{-\gamma_N} \quad K_N = \text{constant}$$

2) Form Positive
Illuminate *Negative*, project onto second film.



On second film, intensity

$$g(x,y) = T_N(x,y)$$

Second film has γ_P and exposure τ_P, transmission

$$\begin{aligned} T_P &= K_P(g\tau_P)^{-\gamma_P} \\ &= K_P(K_N\tau_P)^{-\gamma_P}(f\tau_N)^{\gamma_N\gamma_P} \\ &= K(f\tau_N)^{\gamma_N\gamma_P} \end{aligned}$$

So if we choose $\gamma_N\gamma_P = 1$ then we have

$$T_P(x,y) \propto f(x,y)$$

the original incident intensity.

Intensity Linearity possible

Negatives in Coherent Light

Form a negative with intensity $f(x,y)$, intensity transmittance

$$T = K(f\tau)^{-\gamma}$$

where for coherent light $f(x,y) = |u(x,y)|^2$.

Illuminate negative with coherent light, want **Amplitude Transmittance**.

Illuminate with constant beam, transmitted amplitude is

$$v(x,y) = \sqrt{T(x,y)}$$

assuming that there is no optical path differences in the negative, (no phase effects).

Define: Amplitude Transmittance,

$$T_a = \sqrt{T} = 10^{D_0/2}(f\tau)^{-\gamma/2}$$

which we will usually write as:

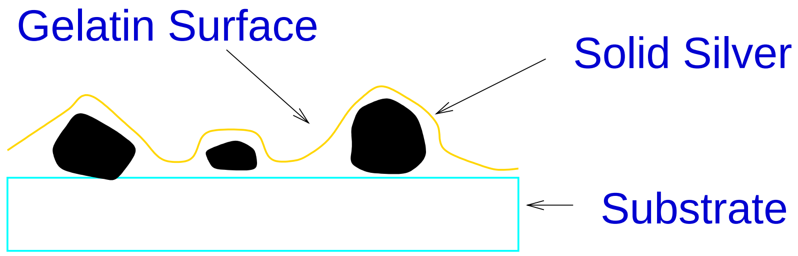
$$T_a = \sqrt{K}(f\tau)^{-\gamma/2} \quad K = \text{constant}$$

Key Result

This will be used in holography in the next lecture.

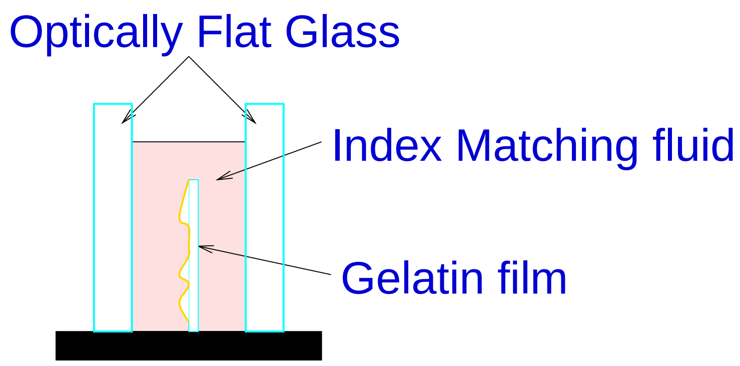
Practical Problem

Gelatin surface **not** flat after development



"Shrinks" to cover solid silver, (also cracks). "Dips" of up to 2μm common, so sever phase problem.

Solution: Optical Gate:



Use oil/solvent with same refractive index as gelatin, ($n = 1.53$)

Light silicon oil or xylene (both rather unpleasant).

Optical gate required when critical optical measures are being made.