# INVESTIGATIONS in PHOTOCHEMICAL ENGINEERING for MOTION PICTURE FILM

*Part I: The Handmade, Silver Gelatin Emulsion*


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- Relative Atomic Mass (Ar)
- Mole (mol)
- Molarity (ci)
- Molar Mass

Molar Masses
- Water | H2O
- Silver Nitrate | AgNO3
- Potassium Bromide, Anhydrous | KBr
- Potassium Iodide| KI
- Sodium Chloride | NaCl
- Sodium Bromide | NaBr
- Ammonium Bromide | NH4Br

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# Preface to the *Investigations* series

<u>Proposed Test</u>

*Below is a list of proposed test for the Investigation Series. Not all of these test will be performed in the course of this series, but it gives an impression of areas which we would like to focus on…*

**Emulsion Testing**

- Materials
    - Quality of Silver (i.e. silver nitrate of different purity and/or sources)
    - Quality of Gelatin (i.e. gelatins of different characteristics, both inert and active)
- Emulsification
    - Quantity of gelatin
        - Initial quantity
        - Final quantity
    - Methods of emulsification
        - Single Jet
        - Double jet
    - Methods of Addition
        - Subsurface addition
        - Surface addition
    - Ripening Agents
        - Boiled Emulsion
        - Ammoniacal Emulsion
    - Emulsification Time & Addition Rates
        - Single Emulsification
        - Multiple Emulsification
    - Emulsification Times
- Washing
    - Chemical Washing
- Sensitization
    - Chemical Sensitization
        - Sulfur
        - Gold
        - Sulfur + Gold
    - Spectral Sensitization
- Finals
    - Hardeners
    - Stabilizers
    - Plasticizers
    - Etc
- Coating
    - Methods
        - Brush
        - Airbrush
        - Trough
        - Extruder
        - Cascade

## Preface to Part I

*In this portion of the series, we will be focusing mainly on presenting the basic information on emulsion theory and techniques. However, we will also be performing various test concerning both the materials used in our emulsions as well as the techniques implemented in emulsification. These test are illustrated in the resource section of this document.*

## Prior to the Seminar

*Any work needing to be complete prior to the workshop will need to be facilitated several days in advance of the workshop date. This includes....*

- Acquisition of materials and equipment
- Preparation of leader for coating in the workshop
- Inspection of all necessary facilities
- Inspection of all necessary equipment
- Preparation of materials & equipment for the workshop
    - Sterilization of all glassware

## Day I [8 hours]

*This day will be dedicated to discussions and demonstrations concerning the theory and technique of emulsion chemistry. Practical exercises will be limited, but not excluded...*

<u>Introduction [0.5 Hours]</u>

1. *Kodak* (Tacita Dean, 2006)
2. Personal Introductions
3. Introduction to the *Investigations* series
4. Introduction to handmade emulsion
    a. Kodak 3383: A discussion concerning commercial manufacturing versus handmaking emulsion

<u>Review of Equipment [0.33 Hours]</u>

1. Safety Equipment
    a. Gloves
    b. Apron
    c. Goggles / Safety Glasses
    d. Respirator
2. Emulsion Making
    a. Essential Equipment
        i. Thermometers
            1. Partial Immersion v. Total immersion
            2. Alcohol v. Mercury
        ii. Hot Plate
        iii. Scale (0.1 gram resolution)
        iv. Safelight
        v. Non metallic (or rust-free, stainless steel) heating vessel
            1. Honeywell processing tanks
    b. Intermediary Equipment
        i. Mag-Stirrer
        ii. Teflon magnets
        iii. Syringes, 100.0 Milliliters or greater

- iv. Glassware
  1. Glass stirring rods
  2. Beakers, 1.0 Liter - 100.0 Milliliters
  3. Graduated cylinders, 1.0 Liter - 25.0 Milliliters
  4. Buchner funnel
- v. Noodle press
- vi. Washing station

c. High End Equipment
- i. Dedicated equipment
- ii. Peristaltic Pumps
- iii. Meters
  1. pH meters
  2. pAg meters
  3. Viscosity meters
- iv. Duplex Safelights

3. Coating
   a. Basic Equipment
      - i. Brushes
   b. Intermediary Equipment
      - i. Airbrush Systems
      - ii. Emulsion Coating Blades
   c. Small Scale Production
      - i. Trough coating systems
      - ii. The Australian job

<u>Review of Materials [0.33 Hours]</u>

1. Silver halide chemistry
   a. Silver nitrate [$AgNO_3$]
   b. Halogen salts
      - i. Potassium Bromide [KBr]
      - ii. Potassium Iodide [KI]
      - iii. Sodium Chloride [NaCl]
2. Gelatin
3. Finals
   a. Hardeners
      - i. Chrome alum [$KCr(SO_4)_2$]
   b. Surfactants
      - i. Wetting agents
      - ii. Ethyl alcohol
      - iii. Distilled water
4. Misc.
   a. Distilled water
   b. Ice

<u>Review of Facilities [0.33 Hours]</u>

1. The Ideal Space
   a. Emulsification Room
      - i. Dust free
      - ii. Contamination free
      - iii. Proper safelights

    b. Coating Room
        i. Dust free
        ii. Contamination free
        iii. Proper safelights
    c. Storage
    d. Testing
        i. Darkroom
2. Inspection of our space

<u>Emulsion Making [1.5 Hour]</u>

1. Preparing all equipment & facilities for emulsion making
    a. Darkroom etiquette
    b. Cleaning and sterilization of all labware
    c. Safelight check
2. Review of emulsion formula
    a. Molecular ratios
    b. Deciding on variations for the formula
3. Emulsification
    a. Preparation of stock solutions
        i. Handling of chemistry
        ii. Measurement procedures
    b. Bringing stock solutions to temperature
    c. Methods of addition
        i. Single Jet & Double Jet
        ii. Surface Addition & Subsurface Addition
    d. Duration of addition
4. Physical Ripening (a.k.a. Ostwald ripening)
    a. Formation of complex ions
        i. Excess halide (neutral emulsion)
            1. $AgBr_2$-, $AgBr_3$--, $AgBr_4$---
        ii. Ammonia [$NH_3$] (ammoniacal emulsion)
            1. $Ag(NH_3)_2$+
    b. Cannibalization
        i. Trending towards lower energy states
5. Washing
    a. "Noodling"
    b. Washing systems
6. Sensitization
    a. Native spectral sensitivity
        i. AgBr
        ii. AgCl
        iii. AgI
    b. Chemical sensitization
    c. Spectral sensitization
7. Finals
    a. Surfactants
    b. Hardeners
8. Storage

<u>Coating Emulsion [1 hour]</u>

1. Preparation of the base for coating
    a. Subbing raw acetate leader
        i. Formulating a substratum layer
        ii. Coating the substratum layer
        iii. Advantages/Disadvantages
    b. Using “found footage”
        i. Methods for preparing fogged stock for coating
            1. Fix in hardening fixer followed by plain water rinsing
            2. Rinse in clearing bath followed by plain water rinsing
            3. Rinse in water with added surfactant
            4. Dry
        ii. Methods for preparing processed found footage (B&W) for coating
            1. Bleach in reversal bleach followed by plain water rinsing
            2. Rinse in clearing bath followed by plain water rinsing
            3. Rinse in water with added surfactant
            4. Dry
2. Coating methods
    a. Brushing procedures
    b. Airbrushing procedures
3. Small strip coating
    a. Plate systems
4. Long strip coating
    a. Looping system
    b. Non-looping systems

<u>The Silver Gelatin Emulsion [1 Hour]</u>

1. Film Anatomy
    a. Base
        i. Cellulose Nitrate (1888-1952)
            1. Flammable
        ii. Cellulose Diacetate (1909-1948)
        iii. Cellulose Triacetate (1948-present)
            1. Non-flammable
            2. Low stability
                a. Decomposes to acetic acid (i.e. vinegar syndrome)
            3. High solubility
                a. Acetone
        iv. Polyethylene Terephthalate (1948-present)
            1. Non-flammable
            2. High stability
            3. High durability
            4. Low solubility
                a. Ultrasonic splicing
    b. Substratum Layer
        i. Gelatin
        ii. Tanning agent
        iii. Base solvent
    c. Emulsion
        i. Silver Halide (AgHal)
            1. Architecture

        a. Main constituents
            i. Silver cations (+)
                1. Ionic radius: 1.26 Å (Ångström)
            ii. Halogen anions (-)
                1. Bromide anions
                    a. Ionic radius: 1.81 Å
                    b. Halide solubility, in water: $2 \times 10^{-8}$ g. moles/L
                    c. Halide color: pale yellow
                2. Chloride anions
                    a. Ionic radius: 1.96 Å
                    b. Halide solubility, in water: $1.33 \times 10^{-5}$ g. moles/L
                    c. Halide color: white
                3. Iodide anions
                    a. Ionic radius: 2.20 Å
                    b. Halide solubility, in water: $7.12 \times 10^{-7}$ g. moles/L
                    c. Halide color: pale yellow (deeper hue than bromide)
        b. The cubic lattice
            i. Cubic grains
                1. 100 Faces
                2. 111 Faces
            ii. Tabular grains
ii. Gelatin
    1. Function and important characteristics of gelatin
        a. Suspension of AgHal grains
        b. Reversible gelling properties
        c. Swelling of gelatin in aqueous solutions
        d. Restraint on the growth of the AgHal
    2. Manufacturing
        a. Animal bones / hide →
        b. Inorganic material removed (i.e. calcium phosphate) leaving ossein →
        c. Through liming, the collagen is broken down into amino-acid chains (gelatin) →
        d. Gelatin is extracted from the limed ossein
    3. Chemical Properties
        a. Amino-acid backbone
            i. Adsorption by the AgHal
        b. Crosslinking groups
            i. Carboxyl groups with inorganic salts (chromium salts)
            ii. Free amino groups with organic bifunctional reagents (formaldehyde)
        c. Sulphur sensitizers
            i. Active Gelatin (1888-1940)
                1. Degradation of cysteine amino acid
                    a. 10-200 ppm of thiosulphate
            ii. Inert Gelatin (1940-present)
                1. Sensitizers
                    a. Sodium Thiosulfate [$Na_2S_2O_3$]
                    b. Sodium Thiocyanate [NaSCN]
        d. Bromine acceptors
        e. Restrainers
    4. Substitutions
        a. ““Such a remarkable combination of useful characteristics seems almost more

than coincidence, and one feels that the Almighty must have created the cow with photography in mind. Perhaps the only improvement which one could suggest would be the inclusion of silver halide in the cow."
- Dr. D.C. Baines, The Science of Photography

iii. Dye Sensitizers
iv. Silver Grain
v. Dye Couplers
vi. Dye Clouds

d. Supplemental layers
    i. Anti-halation layer
    ii. Supercoat
    iii. Back coating
    iv. Lubricants

<u>The Photochemical Process [0.33 Hours]</u>

1. Some basic terms
    a. Reduction, Reducers
    b. Oxidation, Oxidizers
    c. Ions, Cations, Anions
    d. Photon, Electron, Positive Hole (or
    e. Halogen
2. The latent image
    a. Electrostatic balance of the silver halide crystal
        i. The perfect silver halide crystal
        ii. Dislocations
            1. Edge dislocations
        iii. Defects
            1. Frenkel defects
                a. Interstitial silver ions
    b. Photolytical reduction
        i. Photon annihilation
            1. Exciton
            2. Electron Hole
        ii. Sensitivity centers
        iii. Formation of the latent image
            1. Unstable latent image
            2. Subimage latent image
            3. Reducibility of the latent image
                a. Reciprocity failure
                b. Latensification
                    i. Hypersensitization
                    ii. Concurrent photon amplification
3. Amplification of the latent image (development)
    a. Catalytic reduction of the silver halide crystal
    b. Byproducts of development
        i. Bromide
        ii. Oxidized developer
4. Removal of excessive halides (fixation)
    a. Solubility of silver halides

Testing the Emulsion [1.0 Hour]

1. Simple contact printing procedures
2. Processing procedures
3. Sensitometry
    a. Fog
    b. Speed
    c. Stability

## Day II [8 Hours]

*This day will be dedicated to practical experimentation of emulsion chemistry…*

## Following the Workshop

Documentation

1. Digital transfer of selected pieces
2. Adjustment of notes
3. Distribution of notes to workshop participants

# Workshop Resources

Test Parameters

**Quality of Gelatin**

In this test, we will be varying the quality of gelatin used in the emulsion. The test will consist of two batches…

*E1.0*

This batch will be the control. It follows the recipe outlined in the resource section of this document. The key characteristic in regards to this test is it's use of active gelatin.

*E1.1*

This batch will be a variation of the control wherein the active gelatin is substituted for inert gelatin. All other properties will remain constant

**Emulsification Time and Rates**

In this test, we will be varying both the number of emulsifications and the duration of ripening. The test will consist of four batches…

*E1.0*

This batch will be the control. It follows the recipe outlined in the resource section of this document. The key characteristic in regards to this test is it's use of single emulsification across a set time of ten minutes.

*E1.2*

This batch will be a modification of the control in that it will be emulsified using a double emulsification method. In this, our first emulsification will be the rapid addition across 30 seconds of 30 ml of solution B to bring the emulsion to the optimum pAg level for nucleation. The emulsion will then be allowed to ripen for a period of 15 minutes at 50 C. Afterwards, the remaining portion of solution B will be added across 10 minutes.

*E1.3*

This batch will be a modification of the control in that it will be emulsified using a double emulsification method. In this, our first emulsification will be the rapid addition across 30 seconds of 30 ml of solution B to bring the emulsion to the optimum pAg level for nucleation. The emulsion will then be allowed to ripen for a period of 30 minutes at 50 C. Afterwards, the remaining portion of solution B will be added across 10 minutes.

*E1.4*

This batch will be a modification of the control in that it will be emulsified using a double emulsification method. In this, our first emulsification will be the rapid addition across 30 seconds of 30 ml of solution B to bring the emulsion to the optimum pAg level for nucleation. The emulsion will then be allowed to ripen for a period of 60 minutes at 50 C. Afterwards, the remaining portion of solution B will be added across 10 minutes.

Emulsion Formulary

**E1**[1]

*E1 is a very simple and easy to make emulsion, requiring only the basics in terms of supplies, techniques and equipment. The emulsion is generally fine grain with an exposure index between 1 - 5, though this will depend on your choice of gelatin, among other things…*

| Technical Data | |
|---|---|
| Type | Single Jet, Bromide, Neutral |
| Approx. Shelf Life | 3.00 months |
| Coating Capacity | +/- 25.00 $ft^2$ |
| pH | -- |
| Solution A | |
| Distilled Water | 63.0 ml |
| Potassium Bromide [KBr] | 8.0 g |
| Active Gelatin | 10.0g |
| Solution B | |
| Distilled Water | 63.0 ml |
| Silver Nitrate [$AgNO_3$] | 10.0 g |

1. PREPARATION OF STOCK SOLUTIONS. **Solution A** Add the potassium bromide to the distilled water and dissolve completely. Then, under constant agitation, slowly add the gelatin to the solution. Allow the gelatin to swell (approx. 20 minutes) and then slowly raise the temperature to 50 C. **Solution B** Dissolve the silver nitrate in the water and then slowly raise to 45 degree C
2. EMULSIFICATION. Emulsification should occur under a safelight (Kodak 1 or equivalent) or in complete darkness. Each solutions respective temperature should be maintained across the duration of emulsification. Begin by bring solution A to a rapid agitation followed by the addition of solution B across 10 minutes.
3. RIPENING. No ripening specified.
4. WASHING. No washing specified.
5. SENSITIZATION. No additional sensitization specified.
6. FINALS. Finals can be added at ones own discretion.

[1] Taken from Silver Gelatin: A User's Guide to Liquid Photographic Emulsions (Reed, Martin; Jones, Sarah - 2001) with modifications by Kevin Rice

**E2**[2]

*E2 is another very simple and easy to make emulsion, requiring only the basics in terms of supplies, techniques and equipment. The emulsion is generally fine grain with an exposure index between 1 - 5, though this will depend on your choice of gelatin, among other things…*

| Technical Data | |
|---|---|
| Type | Single Jet, Chloride, Neutral |
| Approx. Shelf Life | 3.00 months |
| Coating Capacity | +/- 25.00 $ft^2$ |
| pH | -- |
| Solution A | |
| Distilled Water | 500.00 ml |
| Sodium Chloride [NaCl] | 12.0 g |
| Active Gelatin | 90.0g |
| Solution B | |
| Distilled Water | 100.0 ml |
| Silver Nitrate [$AgNO_3$] | 25.0 g |

1. PREPARATION OF STOCK SOLUTIONS. **Solution A** Add the sodium chloride to the distilled water and dissolve completely. Then, under constant agitation, slowly add the gelatin to the solution. Allow the gelatin to swell (approx. 20 minutes) and then slowly raise the temperature to 50 degree C. **Solution B** Dissolve the silver nitrate in the water and then slowly raise to 50 degree C
2. EMULSIFICATION. Emulsification should occur under a safelight (Kodak 1 or equivalent) or in complete darkness. Each solutions respective temperature should be maintained across the duration of emulsification. Begin by bring solution A to a rapid agitation followed by the addition of solution B across 10 minutes.
3. RIPENING. Ripen the emulsion for 50 minutes at a temperature of 50 degree C.
4. WASHING. No washing specified.
5. SENSITIZATION. No additional sensitization specified.
6. FINALS. Finals can be added at ones own discretion.

[2] Taken from Silver Gelatin: A User's Guide to Liquid Photographic Emulsions (Reed, Martin; Jones, Sarah - 2001) with modifications by Kevin Rice

Photochemical Formulary

**Kodak D-19**[3]

*Designed as a continuous-tone developer for scientific and technical work, D-19 is a high energy (i.e. high contrast) developer well suited for black and white reversal processes, among others. D-19 has good keeping properties and a high capacity as well.*

| Technical Data | |
|---|---|
| Type | Developer (MQ based, High Energy) |
| Approx. Shelf Life | 3.00 months |
| Capacity | +/- 30.00 $ft^2$ per. 1,000.00 ml |
| pH | 11.0 |
| Stock Solution | |
| Water @ 52.0 C | 750.0 ml |
| Metol [$C_7H_9NO \cdot 1/2H_2SO_4$] | 2.0 g |
| Sodium Sulfite, Anhydrous [$Na_2SO_3$] | 90.0 g |
| Hydroquinone [$C_6H_4(OH)_2$] | 8.0 g |
| Sodium Carbonate (Anhydrous) [$Na_2CO_3$] | 45.0 g |
| Potassium Bromide [KBr] | 5.0 g |
| Water to make… | 1,000.0 ml |

1. MIXOLOGY.
    a. Measure out each constituent separately before proceeding.
    b. Bring water to temperature and dissolve a pinch (approx. 5.0 g per liter) of the sodium sulfite to the solution.
    c. While agitating the solution, dissolve each constituent in the order that they appear in the table above, making sure that each one is dissolved in it's entirely before the next addition.
2. STORAGE. Store the final stock solution in an airtight container. Protect from light when possible.
3. DILUTION. Generally speaking D-19 is used undiluted. Dilution can be used to certain effects, but experimentation would need to be undertaken.
4. RECOMMENDED DEVELOPING TIMES. As always, developing times vary based on a considerable number of factors. The times below are simply starting points for experimentation using the undiluted stock solution…
    a. 1 EI ~ 2.00 minutes
    b. 25 EI ~ 3.00 minutes
    c. 100 EI ~ 5.00 minutes
    d. 200 EI ~ 6.5 minutes

[3] Taken from Photographic Lab Handbook, 5th Edition (Carroll, John S. - 1979)

**Kodak D-76**[4]

*Perhaps the most commonly used black and white developer ever engineered, D-76 is a highly versatile developer which strikes a moderate balance between definition, contrast and tonal reproduction. It's energy levels make it well suited for both black and white positive and negative printing, but it is not recommended for reversal processing.*

| Technical Data | |
|---|---|
| Type | Developer (MQ based) |
| Approx. Shelf Life | 3.00 months |
| Capacity | +/- 30.00 ft² per. 1,000.00 ml |
| pH | 9.0 |
| **Stock Solution** | |
| Water @ 52.0° C | 750.0 ml |
| Metol [$C_7H_9NO \cdot 1/2H_2SO_4$] | 2.0 g |
| Sodium Sulfite, Anhydrous [$Na_2SO_3$] | 100.0 g |
| Hydroquinone [$C_6H_4(OH)_2$] | 5.0 g |
| Borax [$Na_2B_4O_7$] | 2.0 g |
| Water to make… | 1,000.0 ml |

1. MIXOLOGY.
   a. Measure out each constituent separately before proceeding.
   b. Bring water to temperature and dissolve a pinch (approx. 5.0 g per liter) of the sodium sulfite to the solution.
   c. While agitating the solution, dissolve each constituent in the order that they appear in the table above, making sure that each one is dissolved in it's entirely before the next addition.
2. STORAGE. Store the final stock solution in an airtight container. Protect from light when possible.
3. DILUTION. D-76 is traditional used undiluted. However, A variety of dilutions can be made from the stock solution, depending on the desired effect.
4. RECOMMENDED DEVELOPING TIMES. As always, developing times vary based on a considerable number of factors. The times below are simply starting points for experimentation using the undiluted stock solution…
   a. 1 ISO ~ 2.5 minutes
   b. 25 ISO ~ 4.0 minutes
   c. 100 ISO ~ 6.0 minutes
   d. 200 ISO ~ 8.0 minutes

[4] Taken from Photographic Lab Handbook, 5th Edition (Carroll, John S. - 1979)

**HF-1 (Hardening Fixer)**[5]

*This formula is a composed of plain hypo with a diluted quantity of F-5a Hardener.*

| Technical Data | |
|---|---|
| Type | Fixer (Hardening, Acidic) |
| Approx. Shelf Life | *indefinite* |
| Archival Working Capacity | +/- 50.00 ft² per. 1,000.00 ml |
| pH | -- |
| **Stock Solution** | |
| Water @ 52.0 C | 750.0 ml |
| Sodium Sulfite, Anhydrous [$Na_2SO_3$] | 19.0 g |
| Sodium Thiosulfate [$Na_2S_2O_3$] | 240.0 g |
| Boric Acid, Crystals [$H_3BO_3$] | 9.0 g |
| Potassium Alum, Dodecahydrate [$KAl(SO_4)_2.12(H_2O)$] | 19.0 g |
| Acetic Acid (28% Solution) [$CH_3COOH$] | 60.0 ml |
| Water to make… | 1,000.0 ml |

1. MIXOLOGY.
    a. Measure out each constituent separately before proceeding.
    b. Bring water to temperature and, while agitating, each constituent in the order that they appear in the table above, except for the acetic acid.
    c. Reduce the temperature of the solution to approx. 20.0 C and add the acetic acid slowly.
2. STORAGE. Protect from light when possible.
3. DILUTION. Diluting is not recommended for standard fixing procedures.
4. RECOMMENDED FIXING TIMES.
    a. All stocks ~ 7.0 minutes

[5] From Kevin Rice

**CB-1 (Clearing Bath)**[6]

*CB-1 is a very basic formula for a clearing solution.*

| Technical Data | |
|---|---|
| Type | Rinse (Ionic) |
| Approx. Shelf Life | indefinite |
| Archival Working Capacity | +/- 200.00 ft² per. 1,000.00 ml |
| pH | -- |
| **Stock Solution** | |
| Water @ 52.0 C | 750.0 ml |
| Sodium Sulfite, Anhydrous [$Na_2SO_3$] | 100.0 g |
| Sodium Bisulfite [$NaHSO_3$]* | 25.0 g |
| Water to make… | 1,000.0 ml |

**The sodium bisulfite was originally included in this formula to act as a buffer for the solution as it was found that an unbuffered solution lead to excessive swelling of emulsions. However, given today's emulsions, this may not be as significant of an issue. Therefore, it is perfectly safe to exclude this constituent from the formula if needed.*

1. MIXOLOGY.
    a. Measure out each constituent separately before proceeding.
    b. Bring water to temperature and, while agitating,  each constituent in the order that they appear in the table above.
2. STORAGE. Protect from light when possible.
3. DILUTION. A dilution of 1:9 (i.e. 1 part stock to 9 parts water) is recommended. Discard immediately after use.
4. RECOMMENDED CLEARING TIMES.
    a. All stocks ~ 1.0 minute

[6] From Kevin Rice

**R9 Reversal Bleach**[7]

*This formula is a dichromate based, reducing bleach. It is the most commonly quoted formula for use in reversal processing. Additionally, it is a useful cleaner of labware. However, the formula is highly toxic.*

| Technical Data | |
|---|---|
| Type | Bleach (Reducer), Dish Cleaner |
| Approx. Shelf Life | *indefinite* |
| Archival Working Capacity | +/- 200.00 $ft^2$ per. 1,000.00 ml |
| pH | -- |
| Stock Solution | |
| Water @ 20.0 C | 750.0 ml |
| Potassium Dichromate ($K_2Cr_2O_7$)* | 9.5 g |
| Sulfuric Acid, 100% ($H_2SO_4$)** | 12.0 ml |
| Water to make… | 1,000.0 ml |

**Carcinogenic compound: Always handle with full body, eye and respiratory protection.*

***Concentrated acid: Always handle with full body and eye protection. Never add water to acid -- always add acid to water.*

1. MIXOLOGY.
    a. Measure out each constituent separately before proceeding.
    b. While agitating, add each constituent in the order that they appear in the table above.
2. STORAGE. Protect from light when possible.
3. DILUTION. Diluting is not recommended.
4. RECOMMENDED BLEACHING TIMES.
    a. All stocks ~ 2.0 minutes

[7] Taken from Photographic Lab Handbook, 5th Edition (Carroll, John S. - 1979)

Conversions

**Surface Area of Motion Picture Film**

S8mm x 100 ft. = 2.62 $ft^2$
16mm x 100 ft. = 5.25 $ft^2$
35mm x 100 ft. = 11.50 $ft^2$

**Temperature**

[°C] = ([°F] − 32) × (5/9)
[°F] = ([°C] × (9/5)) + 32

**Volume**

Milliliter (ml) = Liter (L) * 1000.0
Milliliter (ml) = US Fluid Ounces (fl.oz) * 29.6
Milliliter (ml) = UK Fluid Ounces (fl.oz) * 28.4

Liter (L) = US Gallon * 3.79
Liter (L) = UK Gallon * 4.55

US Fluid Ounces (fl.oz) = ml * 0.0338
UK Fluid Ounces (fl.oz) = ml * 0.0352

UK Gallon = Liter (L) * 0.22
US Gallon = Liter (L) * 0.264

**Mass**

Grams (g) = Kilograms (kg) * 1000.0
Grams (g) = Ounces (oz.) * 28.35
Grams (g) = Grains (gr) * 0.0648
Grams (g) = Pound (lb) * 453.592

Ounces (oz.) = Grams (g) * 0.0354
Ounces (oz.) = Pound (lb) * 16

Grains (gr) = Grams (g) * 15.432
Grains (gr) = Ounces (oz.) * 437.5

**Mass to Liquid Percentages**

$M$ [g] = $V_R$ [ml] * ($\%_R$ / 100) [g/ml]

Where $\%_R$ is the required percentage, $V_R$ is the required volume in milliliters and M is the mass of the dry ingredient in grams. EXAMPLE: You want a 1 liter, 10% solution of potassium bromide. Therefore…

$$M = 1000 \text{ ml} * (10 / 100) \text{ g/ml}$$
$$M = 100.0 \text{ g}$$

…thus, dissolve 100.0 g to 1000.0 ml to arrive at a 10% solution.

**Liquid Percentage Conversions**

$V_S = (\%_R / \%_S) * V_R$

*Where $V_S$ is the volume of stock needed for dilution in, $\%_R$ is the required percentage, $\%_S$ is the stock percentage and $V_R$ is the required volume. EXAMPLE: You have 28% acetic acid, but the recipe calls for 100.0 ml of 3% acetic acid. Therefore…*

$$V_s = (3/28) * 100.0 \text{ ml}$$
$$V_s = 10.714 \text{ ml}$$

…thus, substitute the 100.0 ml of 3% acetic acid called for in the recipe with 10.714 ml of 28% acetic acid.

Units and Measurements

**Relative Atomic Mass ($A_r$)**

Relative atomic mass is, in it's most basic sense, the sum of each subatomic particles mass (i.e the mass of each proton, neutron an electron) within a given atom. It's value is expressed in atomic mass units (u) which is defined as 1/12th of a Carbon-12 atom at rest.

**Mole (mol)**

The mole is a unit of measurement used to express the amount of a chemical substance. For example, the reaction of di-hyrogen and di-oxygen to form water is written in the following equation:

$$2\ H_2 + 1\ O_2 \rightarrow 2\ H_2O$$

...whereby 2 mol di-hydrogen ($H_2$) + 1 mol di-oxygen ($O_2$) forms 2 mol water ($H_2O$). Additionally, we can also say that within 1 mol $H_2O$, there are 2 mol hydrogen (H) and 1 mol oxygen (O). etc..

Furthermore, a mole is defined as the amount of any substance containing as many specified elementary entities (e.g. atoms, ions, molecules, electrons, etc) as there are atoms in 12 grams of Carbon-12. This number directly correlates to the Avogadro Constant, $6.02214129(27)\times10^{23}$. Therefore...

1 Mol of X = $6.02214129(27)\times10^{23}$ of X (whether X be an ion, molecule, atom, etc…)

**Molarity ($c_i$)**

Molarity (a.k.a. molar concentration) is the amount of a constituent within a mixture (typically in units mol) divided by the volume of the mixture. The calculation for molarity is written as such:

$$c_i = n_i / V$$

...whereby $c_i$ is molarity, $n_i$ is the amount of the constituent in moles, and V is the volume of the mixture.
The unit for molarity is M and is equivalent to 1 mol / 1 Liter. Thus...

0.5 mol $AgNO_3$ / 2 Liter = 0.25 M $AgNO_3$.

**Molecular Mass**

Molecular mass (a.k.a. Molecular Weight) is the sum of the relative atomic masses of each constituent atom multiplied by the number of moles of that element in a molecular formula. For example, water has the molecular formula $H_2O$. In order to calculate its molecular mass, we must figure the relative atomic masses of hydrogen and oxygen...

$A_r$ H = 1.01 u
$A_r$ O = 16.00 u

thus...

$$A_r\ H_2O = (2 \times A_r\ H) + (1 \times A_r\ O)$$
$$A_r\ H_2O = (2 \times 1.01\ u) + (1 \times 16.00\ u) = 18.02\ u$$

**Molar Mass**

Molar mass is the mass of 1 mol of any given substance. Conveniently, this is equal to its molecular mass in units gram. So, for example, with Silver Nitrate ($AgNO_3$), which has a molecular mass of 169.87 u, we can suggest that…

1 Mol AgNO3 = 169.87 grams $AgNO_3$

Molar Masses

**Water | H2O**

| Moles | $x$ | Molar Mass (g) | Subtotal Mass (%) | Subtotal Mass (g) |
|---|---|---|---|---|
| 2 | H | 1.01 | 11.19 | 2.02 |
| 1 | O | 16.00 | 88.79 | 16.00 |
| **1** | **$H_20$** | **18.02** | **100.00** | **18.02** |

**Silver Nitrate | $AgNO_3$**

| Moles | $x$ | Molar Mass (g) | Subtotal Mass (%) | Subtotal Mass (g) |
|---|---|---|---|---|
| 1 | Ag | 107.87 | 63.50 | 107.87 |
| 1 | N | 14.01 | 8.25 | 14.01 |
| 3 | O | 16.00 | 28.26 | 48.00 |
| **1** | **$AgNO_3$** | **169.87** | **100.00** | **169.87** |

**Potassium Bromide, Anhydrous | KBr**

| Moles | $x$ | Molar Mass (g) | Subtotal Mass (%) | Subtotal Mass (g) |
|---|---|---|---|---|
| 1 | K | 39.10 | 32.86 | 39.10 |
| 1 | Br | 79.90 | 67.15 | 79.90 |
| **1** | **KBr** | **119.00** | **100.00** | **119.00** |

**Potassium Iodide| KI**

| Moles | $x$ | Molar Mass (g) | Subtotal Mass (%) | Subtotal Mass (g) |
|---|---|---|---|---|
| 1 | K | 39.10 | 23.55 | 39.10 |
| 1 | I | 126.90 | 76.45 | 126.90 |
| **1** | **KI** | **166.00** | **100.00** | **166.00** |

**Sodium Chloride | NaCl**

| Moles | *x* | Molar Mass (g) | Subtotal Mass (%) | Subtotal Mass (g) |
|---|---|---|---|---|
| 1 | Na | 22.99 | 39.34 | 22.99 |
| 1 | Cl | 35.45 | 60.67 | 35.45 |
| **1** | **NaCl** | **58.44** | **100.00** | **58.44** |

**Sodium Bromide | NaBr**

| Moles | *x* | Molar Mass (g) | Subtotal Mass (%) | Subtotal Mass (g) |
|---|---|---|---|---|
| 1 | Na | 22.99 | 22.34 | 22.99 |
| 1 | Br | 79.90 | 77.66 | 79.90 |
| **1** | **NaBr** | **102.89** | **100.00** | **102.89** |

**Ammonium Bromide | $NH_4Br$**

| Moles | *x* | Molar Mass (g) | Subtotal Mass (%) | Subtotal Mass (g) |
|---|---|---|---|---|
| 1 | N | 14.01 | 14.30 | 14.01 |
| 4 | H | 1.01 | 4.12 | 4.03 |
| 1 | Br | 79.90 | 81.58 | 79.90 |
| **1** | **NH4Br** | **97.94** | **100.00** | **97.94** |

Filmmakers and Selected Works

- Ben Donahue [researcher]
- Alex Mackenzie (http://www.alexmackenzie.ca/)
    - *Logbook* (2011)
    - Various performances
- Lindsay McIntyre
- Robert Schaller (http://www.robertschaller.org/)
    - *Triptych* (1996) [Gum Bichromate Emulsion]
    - *If Not One and One* (1999) [Gum Bichromate Emulsion]
    - *To the Beach* (1999) [Gum Bichromate Emulsion]
- Esther Urulus (http://estherurlus.hotglue.me/)
    - *Konrad & Kurfurst* (2014)

Chemical Suppliers

- ArtCraft Chemicals (http://www.artcraftchemicals.com/) -- *New York based photochemical supplier with a good selection and good prices, particularly for silver nitrate.*
- The Science Company (http://www.sciencecompany.com/) -- *Denver based chemistry and lab equipment supplier. Higher prices than most, but convenient if working in Colorado.*
- Photographers Formulary (http://stores.photoformulary.com/) -- *Montana based photochemical supplier with a moderate selection and good prices. Also sells kits and books.*
- Nymoc Products Co. (https://plus.google.com/111988851146358298635/about?hl=en) -- *Toronto based chemical supplier with the widest selection at the highest cost.*

Literature

The following selection of literature is a comprehensive list of text relating to the workshops subject matter. Highly recommended text for those looking to go in depth with the subject have been marked with an asterisk. Additionally, any hyperlinked text are available to download from Process Reversals website at http://processreversal.org/literary-resources/

- Emulsion
  *NOTE: It's important to understand that any literature dealing with emulsion published before the 1940's assumes the use of photograde ACTIVE gelatin, which is no longer produced. Everything following that assumes the use of inert gelatin.*
    - *Photographic Emulsions* (Wall, E.J. - 1929)
    - *Modern Dry Plates* (Eder, J.M. - 1881)
    - *Photography with Emulsions* (Abney, William De W. - 1885)
    - *The Photographic Emulsion* (Carroll, B.H.; Hubbard, D.; Kretschman, C.M. -1934)
    - *Photographic Emulsion Technique* (Baker, T. Thorne - 1941)*
    - *The Theory of the Photographic Process* (Mees, C.E. Kenneth - 1942)
    - *Photographic Emulsion Chemistry* (Duffin, G.F. - 1966)*
    - *Photographic Sensitivity: Theory and Mechanisms* (Tadaaki, Tani - 1995)*
    - *Dye Transfer Materials* (Browning, James - 1998)
    - *Silver Gelatin: A User's Guide to Liquid Photographic Emulsions* (Reed, Martin; Jones, Sarah - 2001)
    - *Making, Coating and Processing a Simple Gelatin Emulsion* (Osterman, Mark - 2007)
    - *Photographic Emulsion Making, Coating & Testing* (Mowery, Ron - 2009)
    - *Making Kodak Film* (Shanebrook, Robert L. - 2012)
    - *Re:inventing the Pioneers: Film Experiments on Handmade Silver Gelatin Emulsion* (Urulus, Esther - 2013)*
- Sensitometry
    - *General Sensitometry* (Gorokhovskii, Yu. N.; Levenberg, T.M. - 1965)
    - *Photographic Sensitivity: Theory and Mechanisms* (Tadaaki, Tani - 1995)

- Photochemistry
  - *Motion Picture and Television Film: Image Control and Processing Techniques* (Corbett, D.J. - 1968)*
  - *Developing: The Negative Technique* (Jacobson, C.I.; Jacobson, R.E. -1976)
  - *Photographic Lab Handbook, 5th Edition* (Carroll, John S. - 1979)
  - *The Film Developing Cookbook* (Tropp, Bill; Anchell, Stephen G.-1998)*
  - *The Darkroom Cookbook, 3rd Edition* (Anchell, Stephen G. - 2009)*
- Artist Run Film Labs
  - *Kinetica: Lieux d'Experimentations Cinematographiques en Europe* (Gran Lux - 2011)

Web Resources

- Molecular Weight Calculator
- APUG.org
  - Forum: Silver Gelatin Based Emulsion Making & Coating
    - Homemade Film Coating Machine
  - Anything posted by Ron Mowery (Photo Engineer)
- thelightfarm.com
- filmlabs.org
- graphicsatlas.org

# Periodic Table of the Elements