

## SoS RARE - HAPPY FAMILIES

SoS RARE, a project supported by the Natural Environmental Research Council UK (NERC) SoS MinEerals program, is a large interdisciplinary team carrying out research to better understand Rare Earth Element (REE) deposit types, and ensure REE are responsibly sourced. Research includes developing more efficient and environmentally-friendly ways to process REE deposits, and working on metrics to compare deposit characteristics.

More information about SoS RARE can be found on the project website - [sosrare.org](http://sosrare.org) and social media - [@SosRare](https://twitter.com/SosRare)

Each of the cards in this Happy Families set represents an element of interest for given technology applications or metals class, including topical "critical", "strategic", and "green energy" metals. These have been allocated 'family' groups based on uses and characteristics. Family groups are colour coded, but the name for each group is also given down the left hand side of the cards in order to avoid confusion.

Chemical symbol, atomic number, electron arrangement and atomic number are provided for each element, along with information about its discovery, important uses, and the minerals in which it is most commonly found.



## HOW TO PLAY

3 - 6 players

Shuffle and deal all the cards ace down between the players. Play starts with the person to the left of the dealer, who may ask any other player of their choice whether they have cards from a specified family - but they may only ask for a card from a family if they already have a card from that same family in their hand.

Example: player 1 has 'Eu' which belongs to the 'Elements for lighting' family, so they can ask "player 2, do you have any Elements for Lighting?"

If the player being asked has a card in the specified family, they must hand it to the player asking. If they have multiple cards in the family, they are only required to hand over one. The player who asked for and received the card, then gets another go.

Example: player 2 has W & Y, both of which are Elements for Lighting, so they hand player 1 W. Player 1 gets another go.

If the player being asked does not have any of the family specified, play passes on to the next player.

Example: player 1 also has 'Pt' (Jewellery), so they ask "player 3, do you have any Elements for Jewellery?". Player 3 does not, so play passes on to player 2.



## HOW TO PLAY

[cont ...]

Once a player collects all 4 cards in the same family, they place the family down on the table.

The game can either be played to a time limit, to when the first player is out of cards, or to the 'last man standing' when all of the families have been collected.

The aim of the game is to collect the most family sets, or scoring levels for the different families can be agreed in advance - for example the 'Elements for Smartphones' family might be allocated a greater number of points.

Summary of rules:

- You must have at least one card in the family that you are asking another player for
- If you have a card in a family, you must hand it over when asked (if you have multiple, you only need to hand over one)
- If a request is unsuccessful, play passes to the next player
- The winner is the player with the most family groups (or points if families have been allocated different scores)



## ELEMENT

GROUP

CHEMICAL  
SYMBOL

ATOMIC  
NUMBER

FORMULA  
OF EXAMPLE  
MINERAL

ATOMIC  
WEIGHT

DISCOVERED BY:

DISCOVERED IN:

HOST MINERAL: *example mineral, other hosts*

USES:



## RHENIUM

Re

75



PtAs<sub>2</sub>

186.21

**DISCOVERED BY:** *Walter Noddack, Ida Tacke, and Otto Berg (Germany)*

**DISCOVERED IN:** 1925

**HOST MINERAL:** *sperrylite*

**USES:** *alloys, catalysts, cancer treatments, radioactive research, jet engine components*

ELEMENTS FOR SUPERALLOYS



## BERYLLIUM

Be

4



Be<sub>4</sub>Si<sub>2</sub>O<sub>7</sub>(OH)<sub>2</sub>

9.01

**DISCOVERED BY:** *Friedrich Wöhler (Germany) and Antoine Bussy (France)*

**DISCOVERED IN:** 1828

**HOST MINERAL:** *bertrandite*

**USES:** *used in super-light alloys for aerospace applications*

ELEMENTS FOR SUPERALLOYS



## SCANDIUM

Sc

21



(Y,Ca,Ce,U,Th)(Nb,Ta,Ti)<sub>2</sub>O<sub>6</sub>

44.96

**DISCOVERED BY:** *Fredrik Nilson (Sweden)*

**DISCOVERED IN:** 1879

**HOST MINERAL:** *euxenite*

**USES:** *aluminum-scandium alloys for aerospace industry, sports equipment (bicycle frames, fishing rods, baseball bats)*

ELEMENTS FOR SUPERALLOYS



## NIOBIUM

Nb

41



(Na,Ca)<sub>2</sub>Nb<sub>2</sub>O<sub>6</sub>(OH,F)

92.91

**DISCOVERED BY:** *Charles Hatchett (UK)*

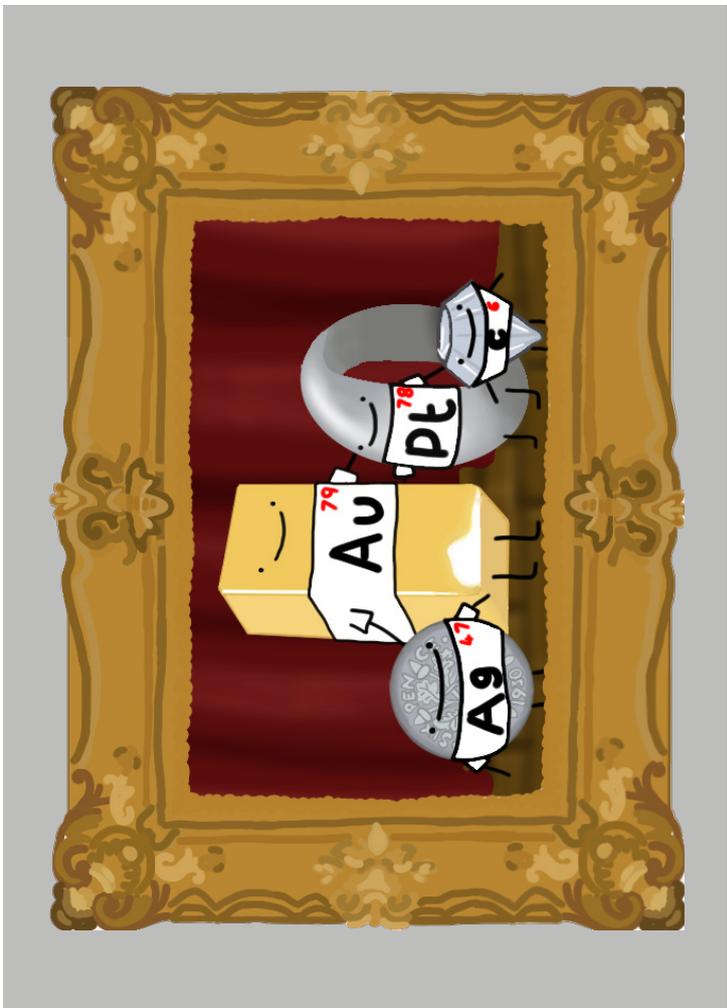
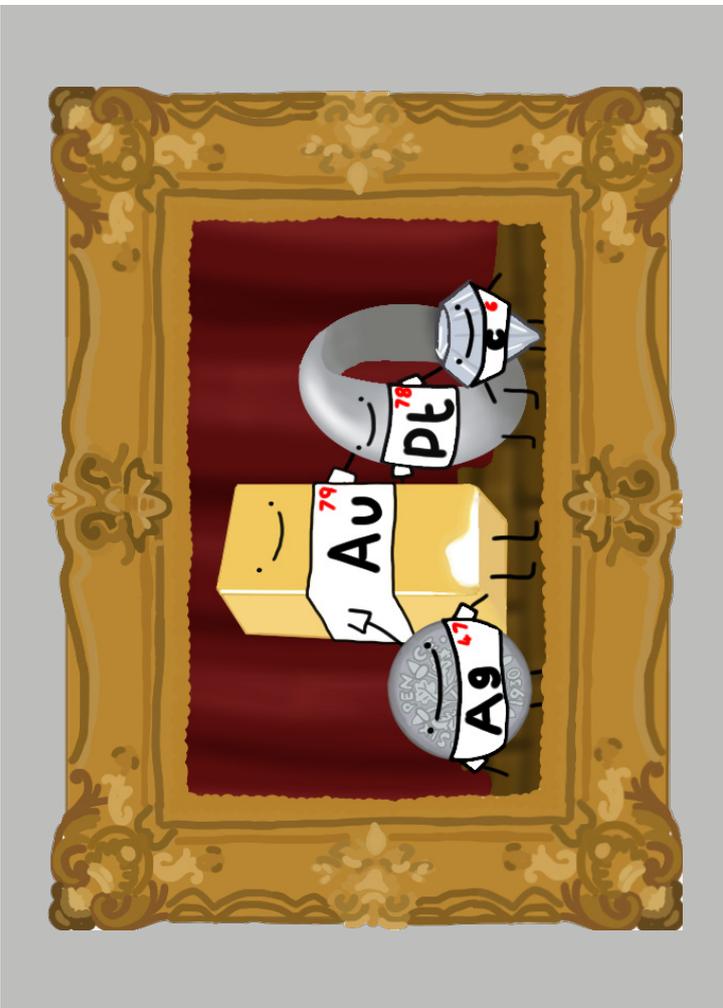
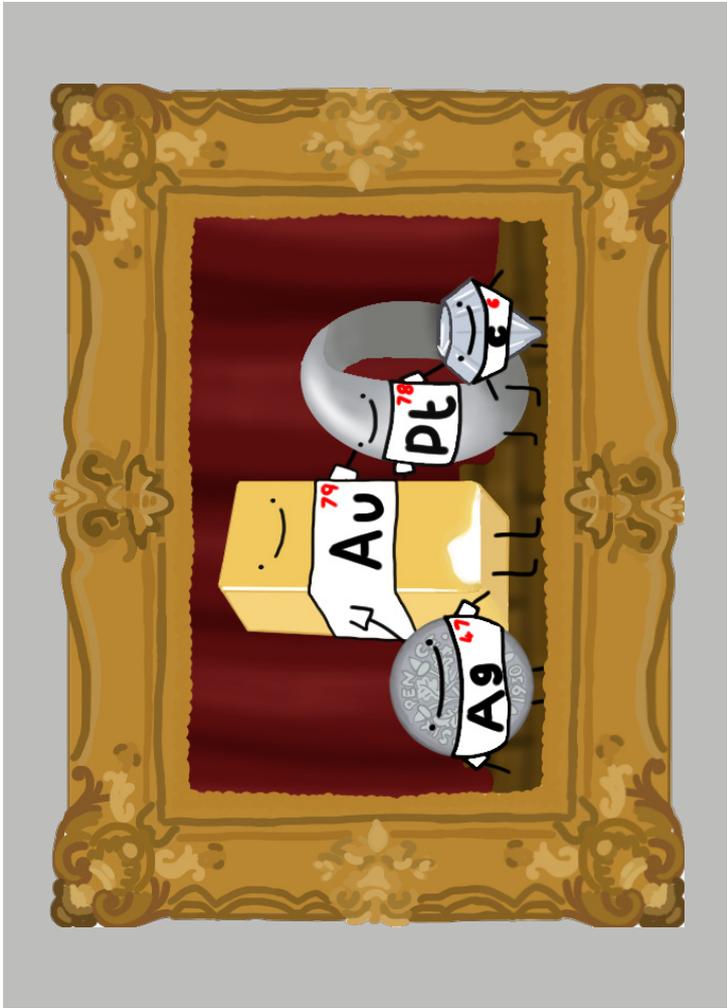
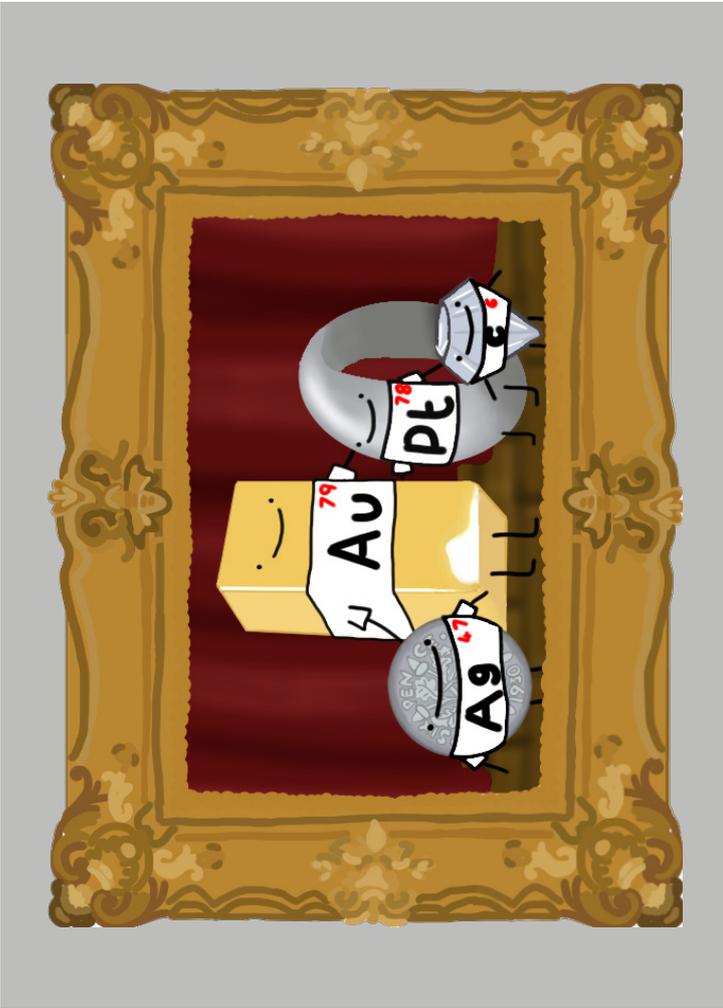
**DISCOVERED IN:** 1801

**HOST MINERAL:** *pyrochlore*

**USES:** *superalloys for jet engines and heat resistant equipment, pipeline construction*

ELEMENTS FOR SUPERALLOYS





## SILVER

ELEMENTS FOR JEWELLERY

Ag

47



Ag<sub>2</sub>S

107.87

DISCOVERED BY: *prehistoric humans*

DISCOVERED IN: *evidence of silver being separated from lead ~ 4th millennium BC*

HOST MINERAL: *argentite, galena*

USES: *currency, jewellery, silverware, medicine, electronics, chemical equipment, catalysis, photography, nanoparticles*



## GOLD

ELEMENTS FOR JEWELLERY

Au

79



Au

196.97

DISCOVERED BY: *prehistoric humans*

DISCOVERED IN: *Bronze Age*

HOST MINERAL: *native gold*

USES: *jewellery, currency, electronics, medicine, food and drink*



## DIAMOND

ELEMENTS FOR JEWELLERY

C

6



C

12.01

DISCOVERED BY: *Antoine Lavoisier (France)*

DISCOVERED IN: *1789*

HOST MINERAL: *diamond*

USES: *jewellery, drill bits, cutting and polishing, heat sink (electronics)*



## PLATINUM

ELEMENTS FOR JEWELLERY

Pt

78



PtAs<sub>2</sub>

195.08

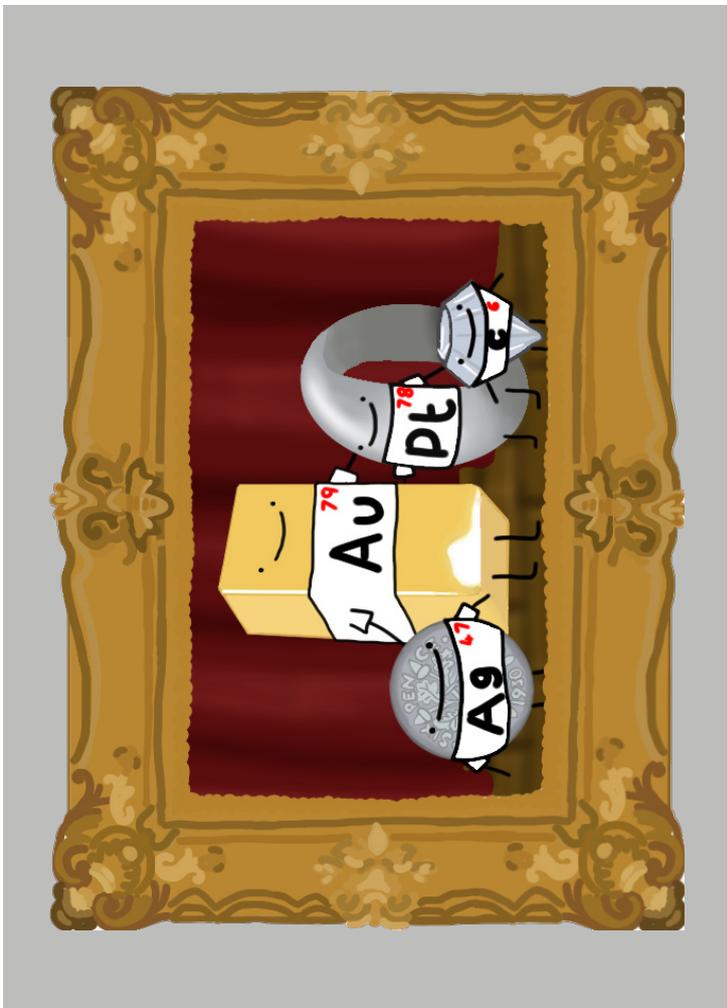
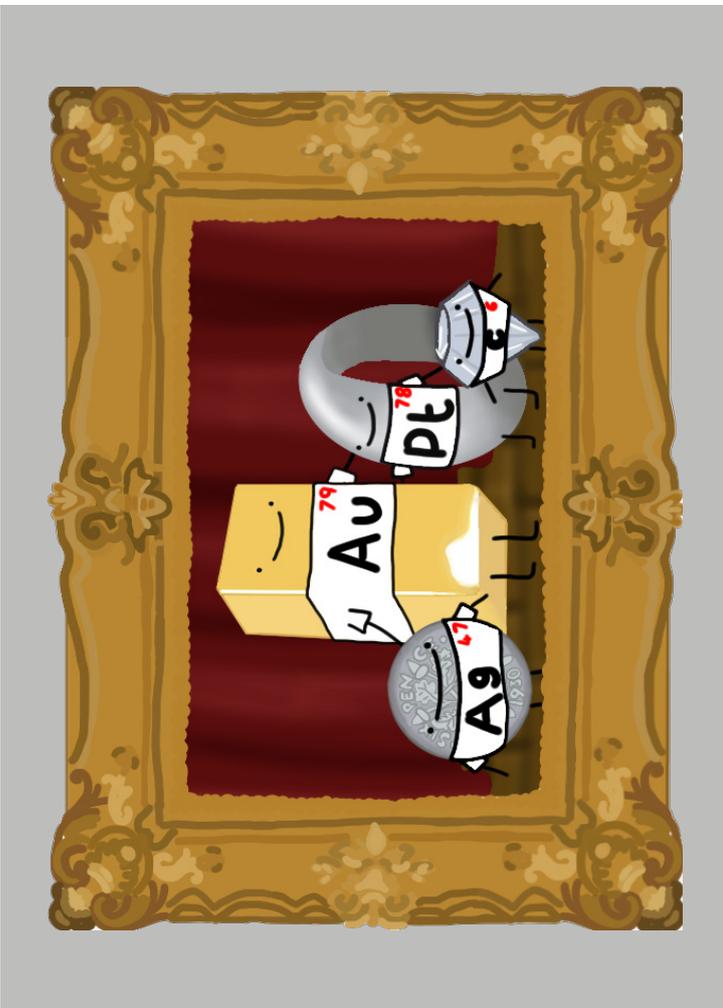
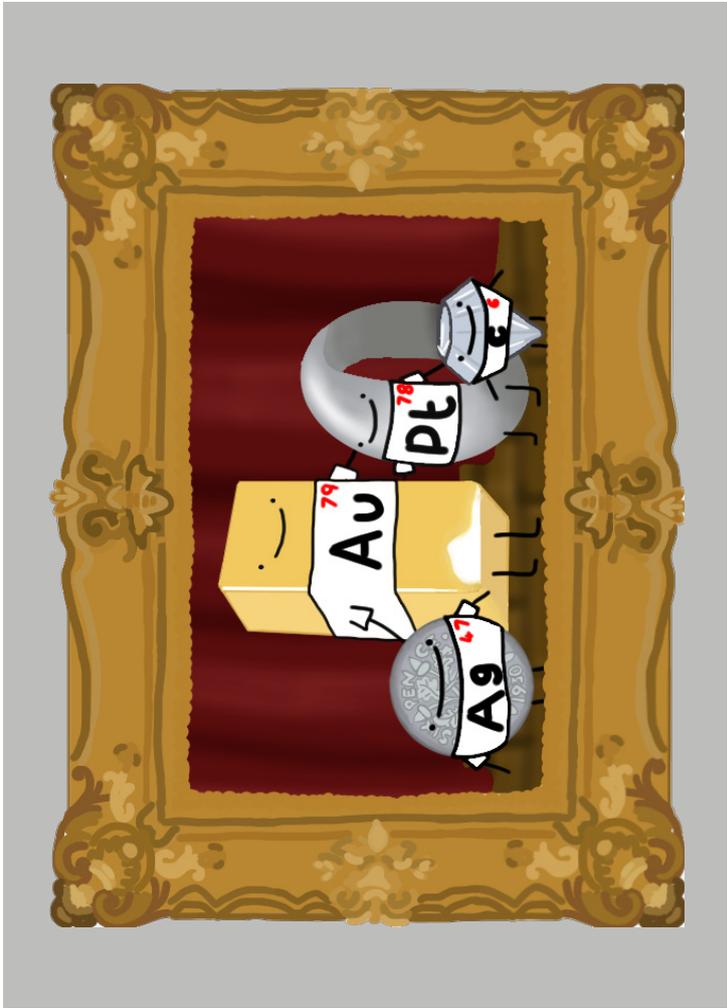
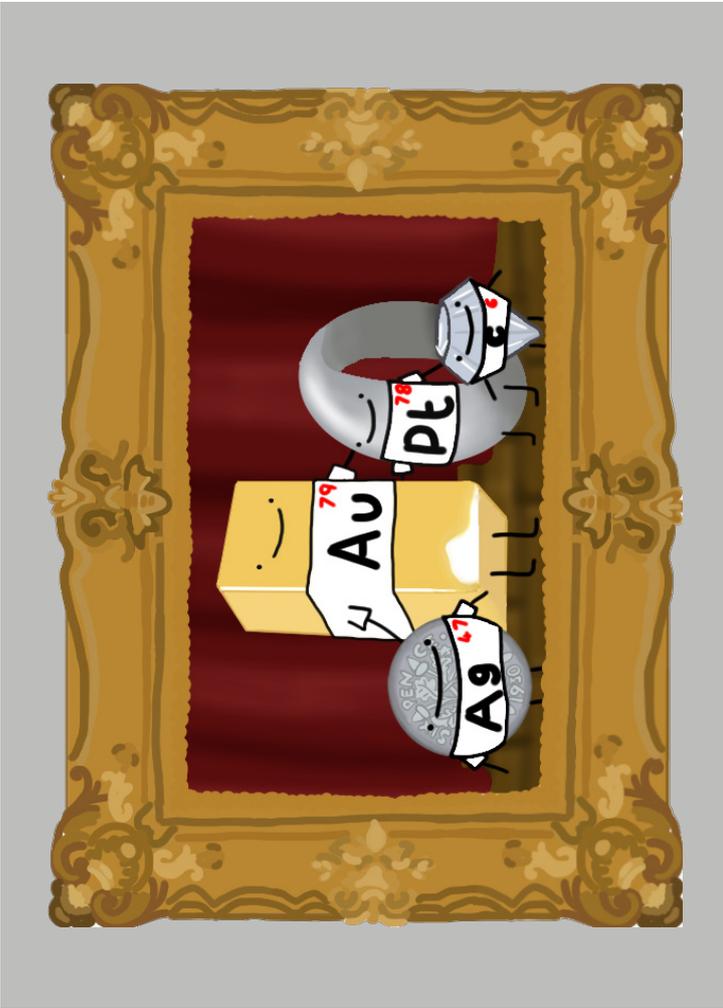
DISCOVERED BY: *Julius Caesar Scaliger (Italian)*

DISCOVERED IN: *1557*

HOST MINERAL: *sperrylite, native platinum*

USES: *currency, jewellery, electronics, lab equipment, catalysis*





## ZINC

Zn

30



(Zn,Fe)S

65.38

DISCOVERED BY: *Andreas Sigismund Marggraf (German)*

DISCOVERED IN: 1746

HOST MINERAL: *sphalerite, smithsonite*

USES: *anti corrosion, batteries, alloys, health supplement, tooth paste, anti dandruff*

ELEMENTS FOR MANUFACTURING

## FLUORINE

F

9



CaF<sub>2</sub>

18.99

DISCOVERED BY: *Henri Moissan (France)*

DISCOVERED IN: 1886 (*isolated*)

HOST MINERAL: *fluorite*

USES: *flux in steel making, sodium fluoride is used in toothpaste and in drinking water to prevent dental cavities*

ELEMENTS FOR MANUFACTURING

## LEAD

Pb

82



PbS

207.20

DISCOVERED BY: *unknown*

DISCOVERED IN: *in use since ~7000 BC*

HOST MINERAL: *galena, cerussite*

USES: *bullets, batteries, sheathing material, roofing material, cladding, flashing, gutters and gutter joints, roof parapets*

ELEMENTS FOR MANUFACTURING

## IRON

Fe

26



Fe<sub>2</sub>O<sub>3</sub>

55.85

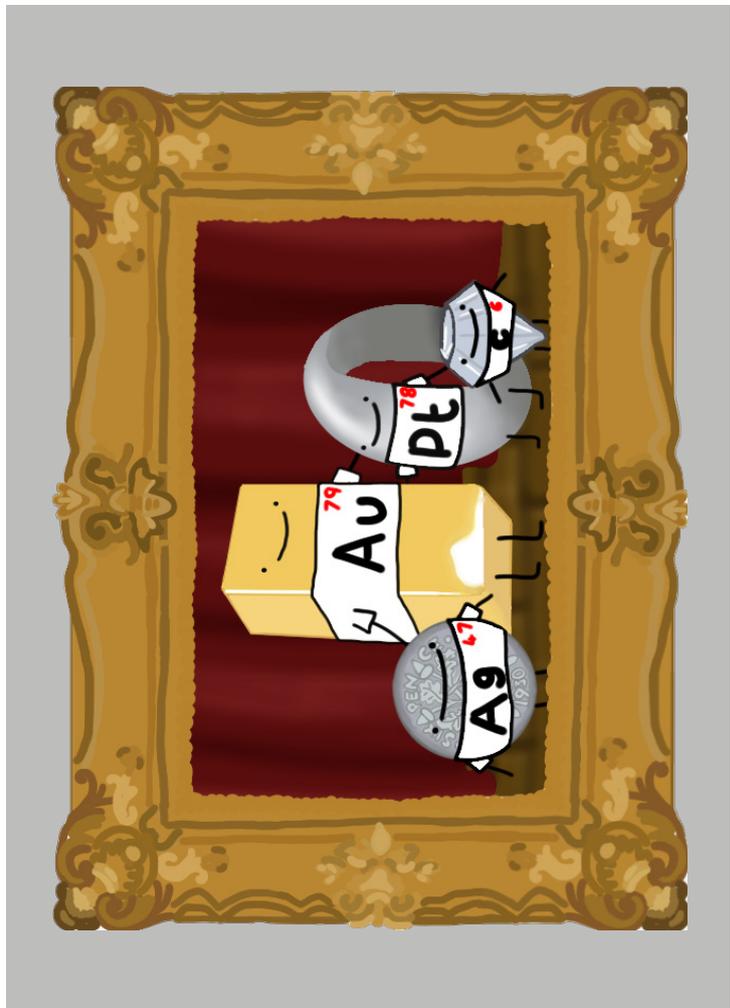
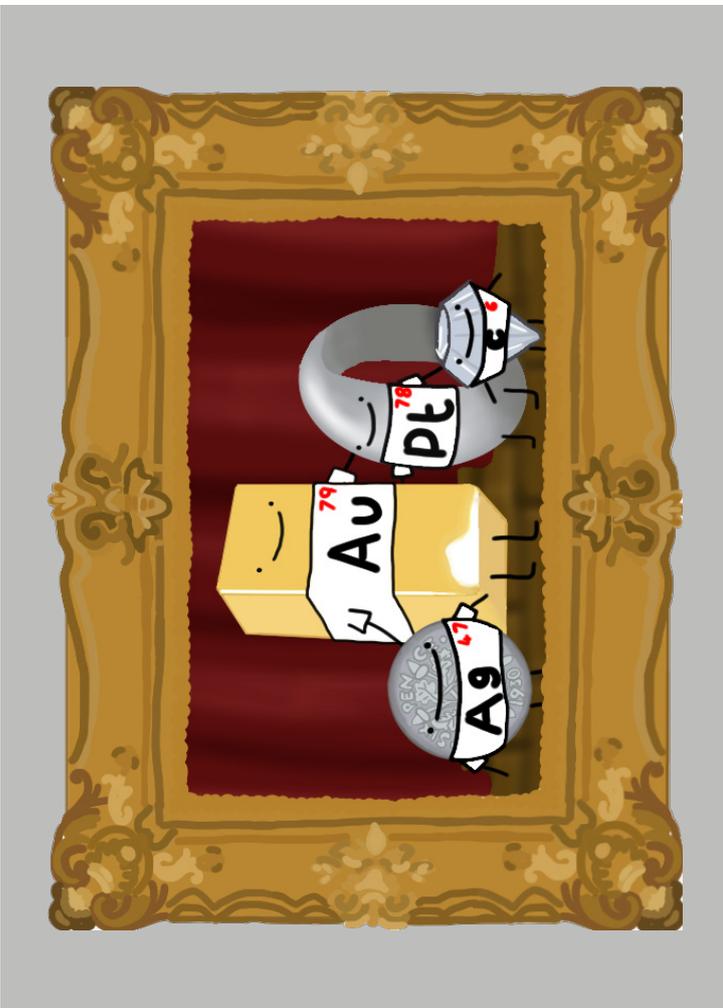
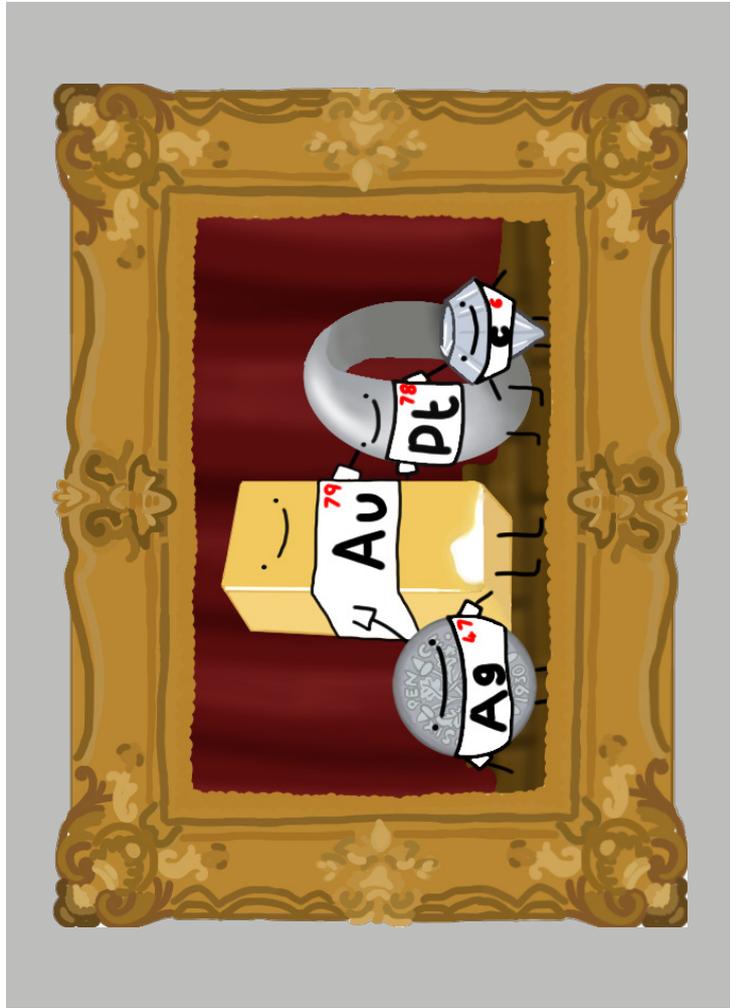
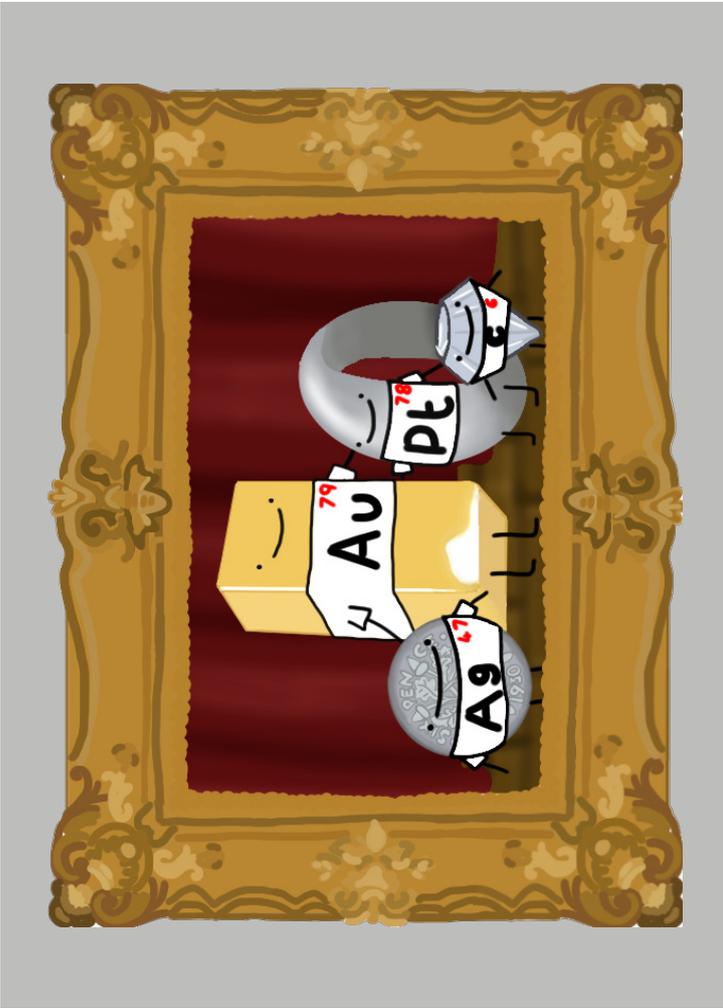
DISCOVERED BY: *unknown*

DISCOVERED IN: *in use since ~3500 BC*

HOST MINERAL: *hematite, magnetite*

USES: *welding, purifying ores, steel, health supplement*

ELEMENTS FOR MANUFACTURING



## COPPER

Cu 29

CuFeS<sub>2</sub> 63.55DISCOVERED BY: *unknown*DISCOVERED IN: *in use since ~9000BC*HOST MINERAL: *chalcopyrite, malachite, native copper*USES: *electronics, wiring, decorative plates, paint pigments, coinage, bacteriostatic agents, fungicides, wood preservatives*

## TANTALUM

Ta 73

(Fe,Mn)Ta<sub>2</sub>O<sub>6</sub> 180.95DISCOVERED BY: *Anders Ekeberg (Sweden)*DISCOVERED IN: *1802*HOST MINERAL: *tantalite*USES: *electronic equipment, as a substitute for platinum*

## TIN

Sn 50

SnO<sub>2</sub> 118.71DISCOVERED BY: *unknown*DISCOVERED IN: *Bronze Age*HOST MINERAL: *cassiterite*USES: *Lead-free solder, electronics, tin plating (prevents corrosion), glass making, Li-ion batteries*

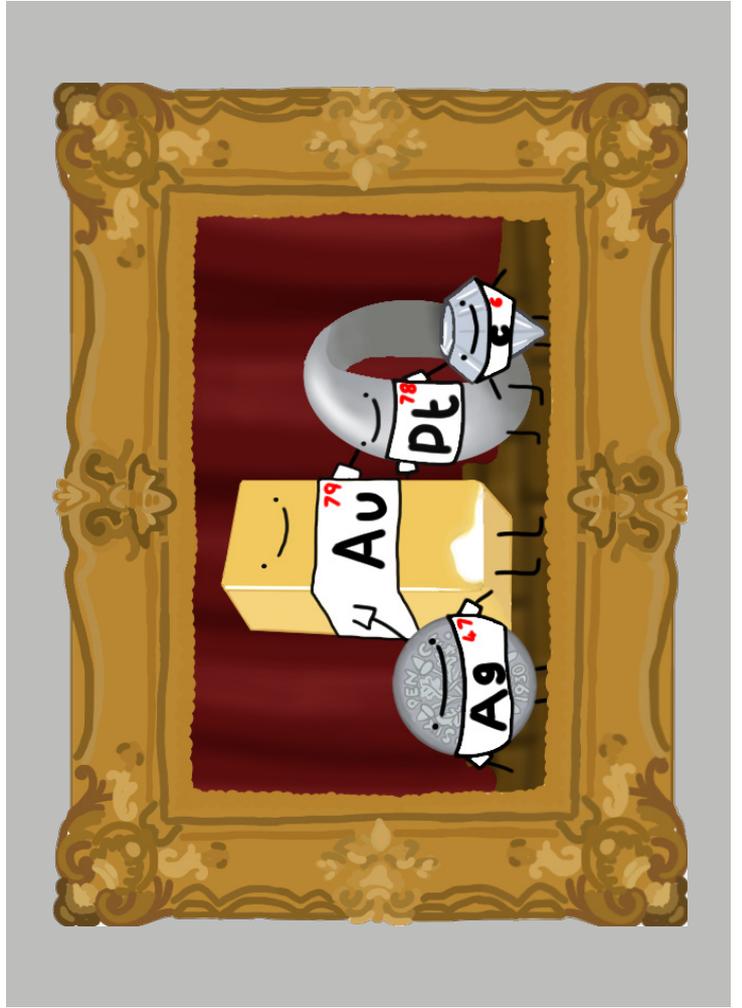
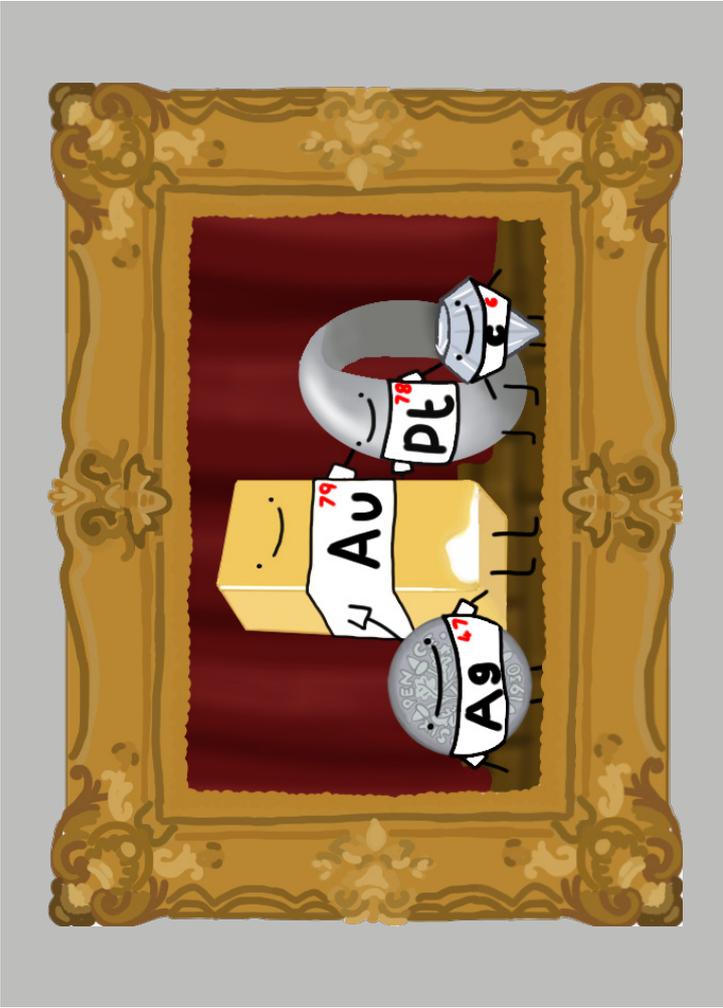
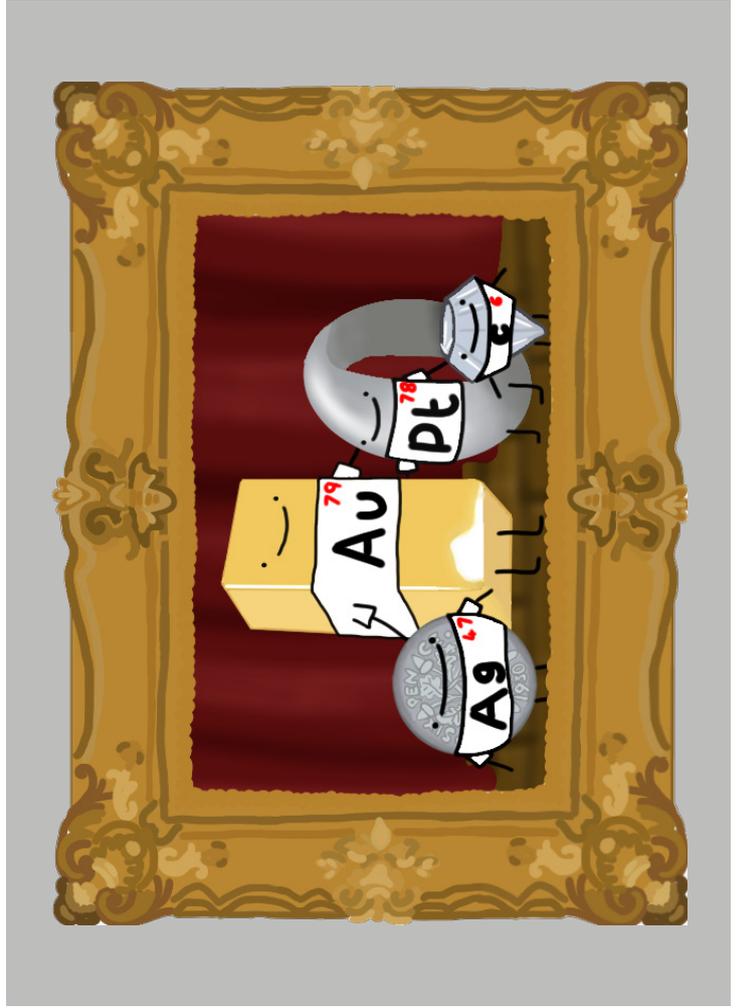
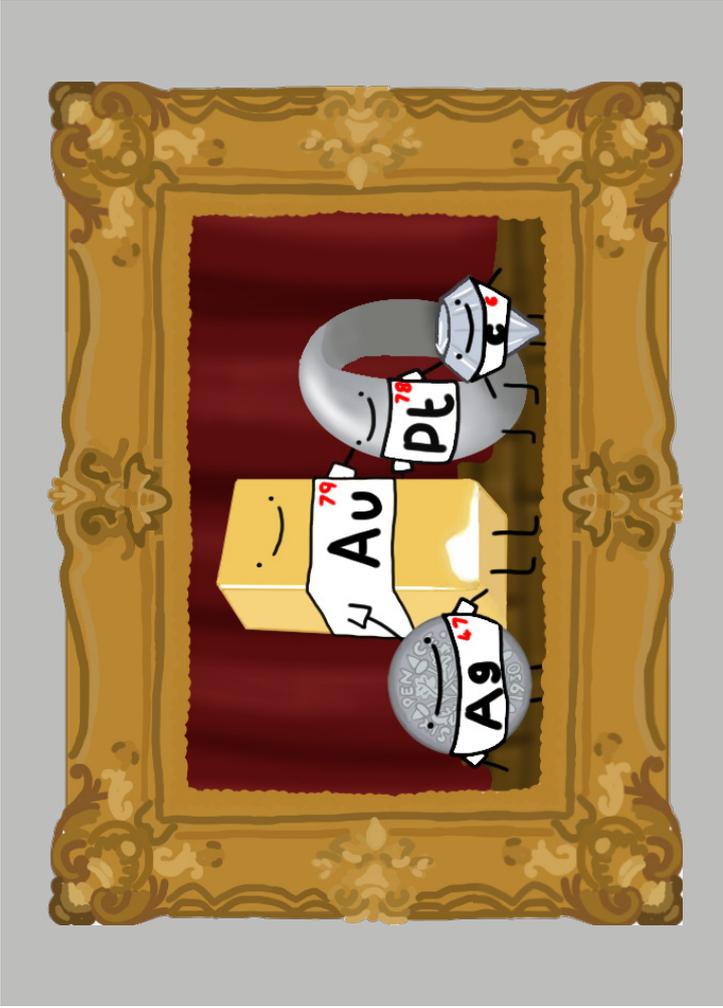
## INDIUM

In 49



(Zn,Fe)S 114.82

DISCOVERED BY: *Ferdinand Reich and Hieronymus Theodor Richter (Germany)*DISCOVERED IN: *1863*HOST MINERAL: *sphalerite*USES: *touch screen technology in mobile phones, semiconductors, high vacuum seals, batteries, as a stabiliser*



# LITHIUM

ELEMENTS FOR BATTERIES

# Li

# 3



$\text{LiAl}(\text{SiO}_3)_2$

6.94

DISCOVERED BY: *Johan August Arfwedson (Sweden)*

DISCOVERED IN: 1817

HOST MINERAL: *spodumene, petalite, brines*

USES: *batteries, ceramics and glass, electronics, lubricating grease, various medical uses*



# CARBON

ELEMENTS FOR BATTERIES

# C

# 6



C

12.01

DISCOVERED BY: *Carl Wilhelm Scheele (Sweden)*

DISCOVERED IN: 1779

HOST MINERAL: *graphite*

USES: *(graphite) electrode in Li batteries, pencils, charcoal, cloth, steel, carbon fibre, printing ink*



# COBALT

ELEMENTS FOR BATTERIES

# Co

# 27



$\text{CoO}(\text{OH})$

58.93

DISCOVERED BY: *Georg Brandt (Sweden)*

DISCOVERED IN: 1735

HOST MINERAL: *heterogenite, cobaltite*

USES: *electrode in Li batteries, alloys, catalysts, pigments and colouring, radioisotopes*



# NICKEL

ELEMENTS FOR BATTERIES

# Ni

# 28



$(\text{Fe},\text{Ni})_9\text{S}_8$

58.69

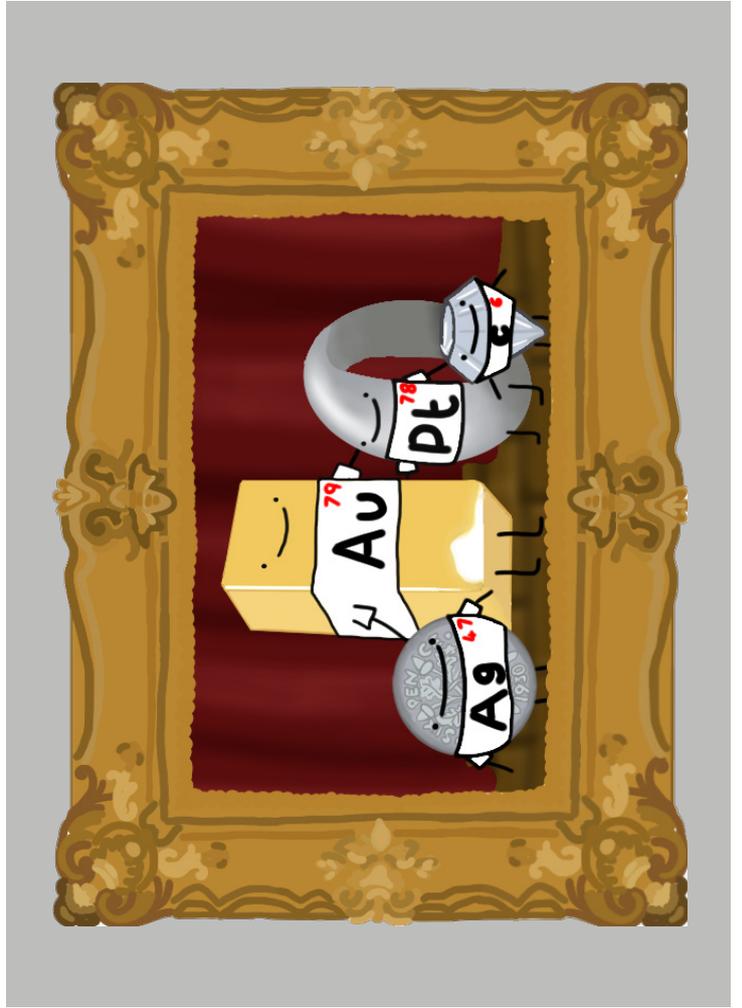
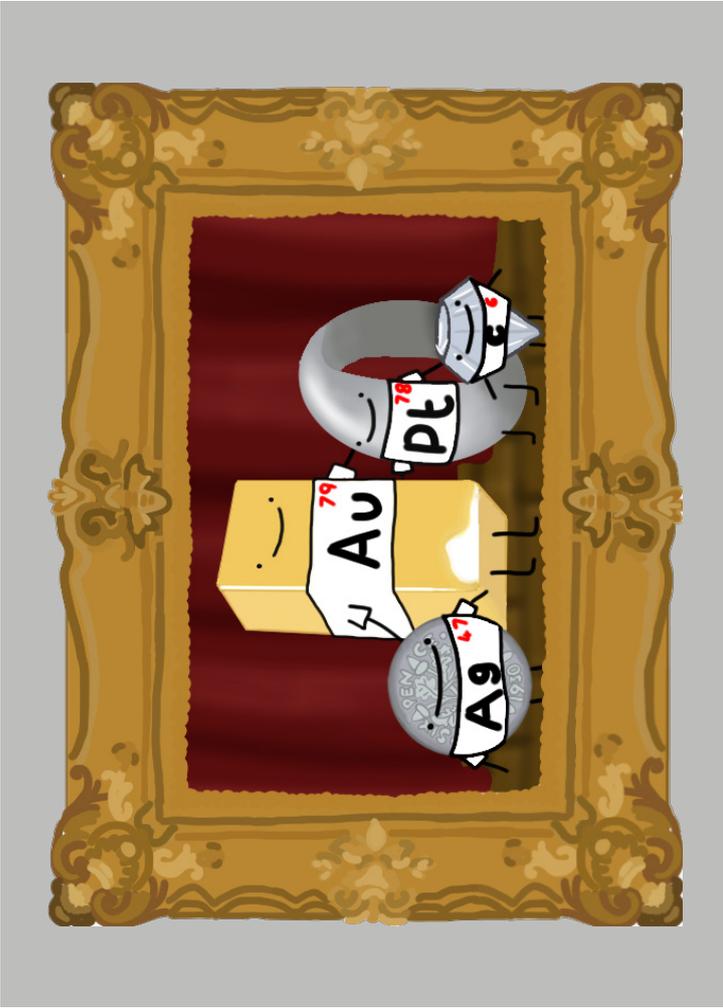
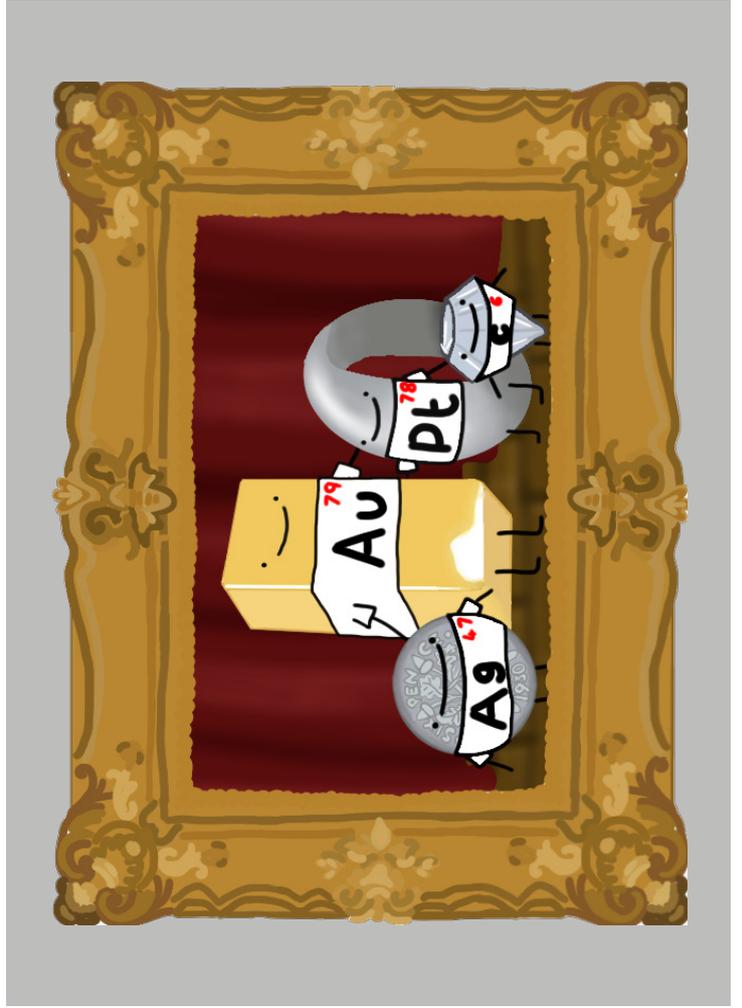
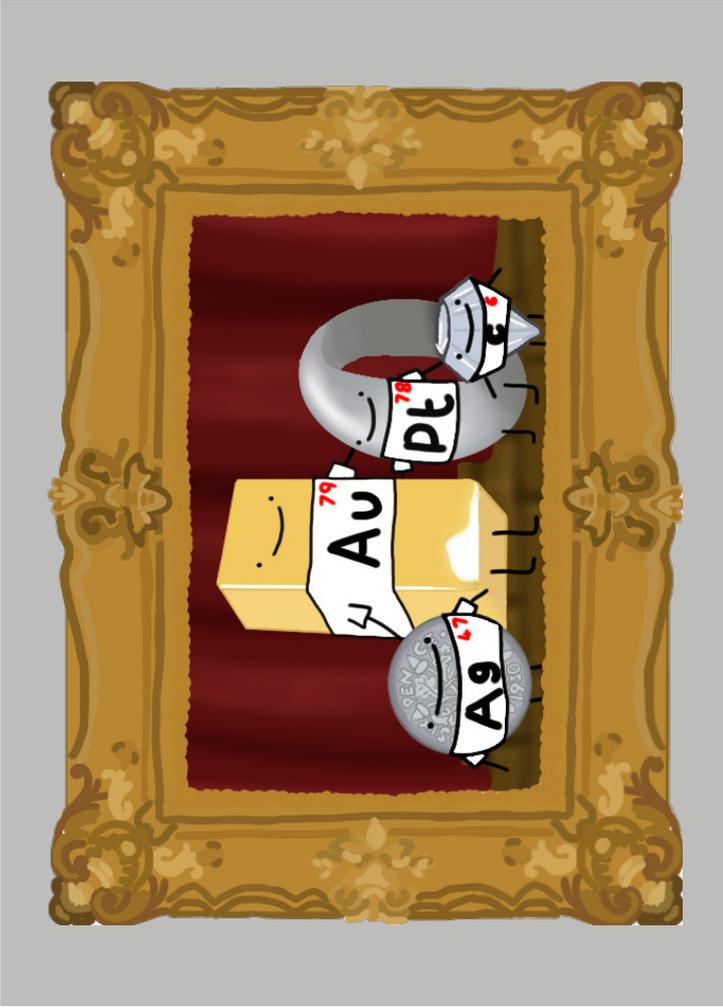
DISCOVERED BY: *Baron Axel Fredrik Cronstedt (Sweden)*

DISCOVERED IN: 1751

HOST MINERAL: *pentlandite, garnierite*

USES: *NiMH (Nickel Metal Hydride) batteries, magnets, electric guitar strings, microphone capsules, plating on plumbing fixtures*





## SILICON

ELEMENTS FOR SOLAR POWER

Si

14



SiO<sub>2</sub>

28.09

**DISCOVERED BY:** *Jöns Jakob Berzelius (Sweden)*

**DISCOVERED IN:** 1823

**HOST MINERAL:** *quartz*

**USES:** *solar power, abrasives and components of high-strength ceramics, cement, computers, mobile phones, synthetic polymers (silicones)*



## SELENIUM

ELEMENTS FOR SOLAR POWER

Se

34



CuFeS<sub>2</sub>

78.97

**DISCOVERED BY:** *Jöns Jakob Berzelius (Sweden)*

**DISCOVERED IN:** 1917

**HOST MINERAL:** *sulphide ores (chalcopyrite) - replacing sulphur*

**USES:** *glass making, pigments, semiconductors, photocells, DC power surge protectors*

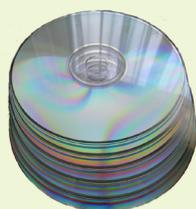


## TELLURIUM

ELEMENTS FOR SOLAR POWER

Te

52



PbTe

127.60

**DISCOVERED BY:** *Franz-Joseph Müller von Reichenstei / Pál Kitaibel (Austria)*

**DISCOVERED IN:** 1782 / 1789

**HOST MINERAL:** *telluride minerals (altaite)*

**USES:** *alloys, solar panels, phase-change memory chips, media layer of rewritable optical discs (CD-RW, DVD-RW, Blu-ray)*



## GALLIUM

ELEMENTS FOR SOLAR POWER

Ga

31



(Zn,Fe)S

69.72

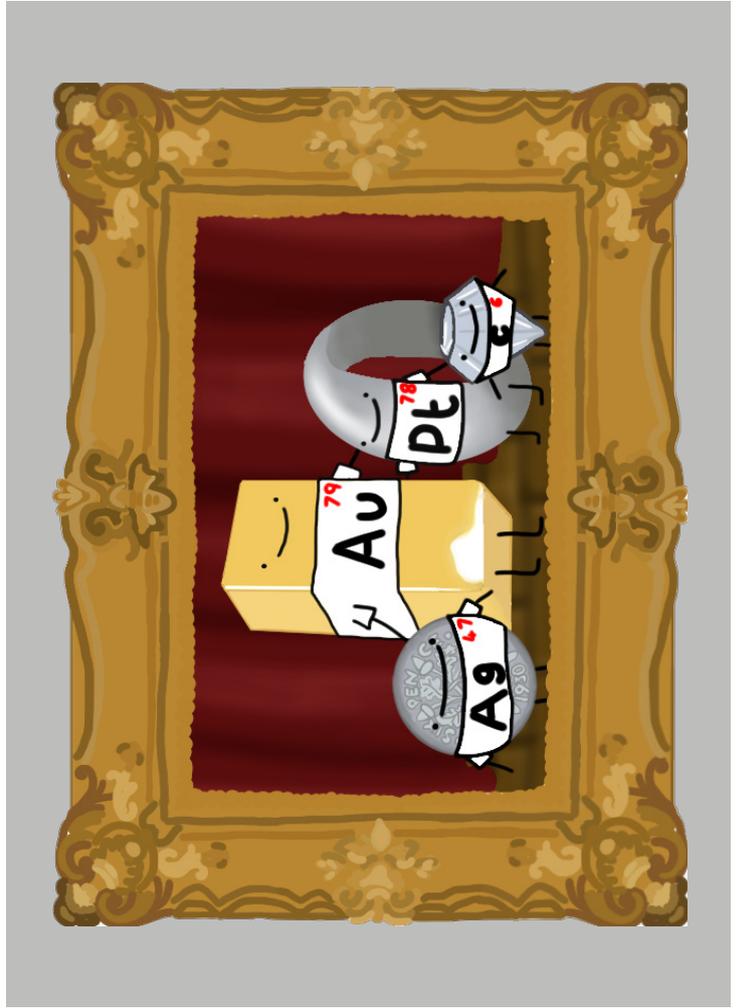
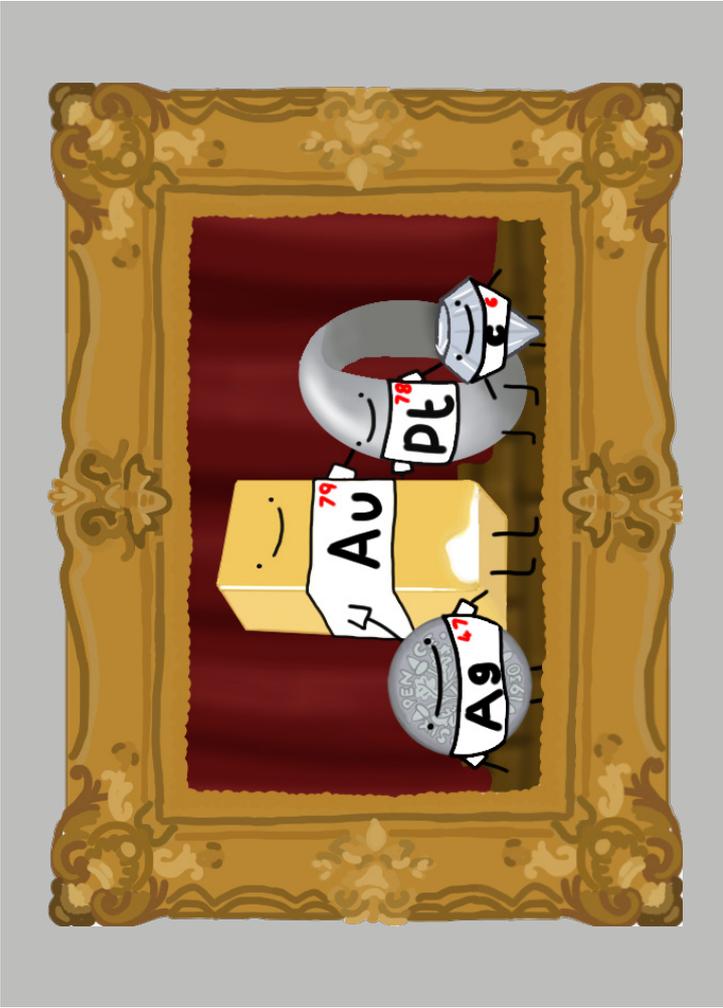
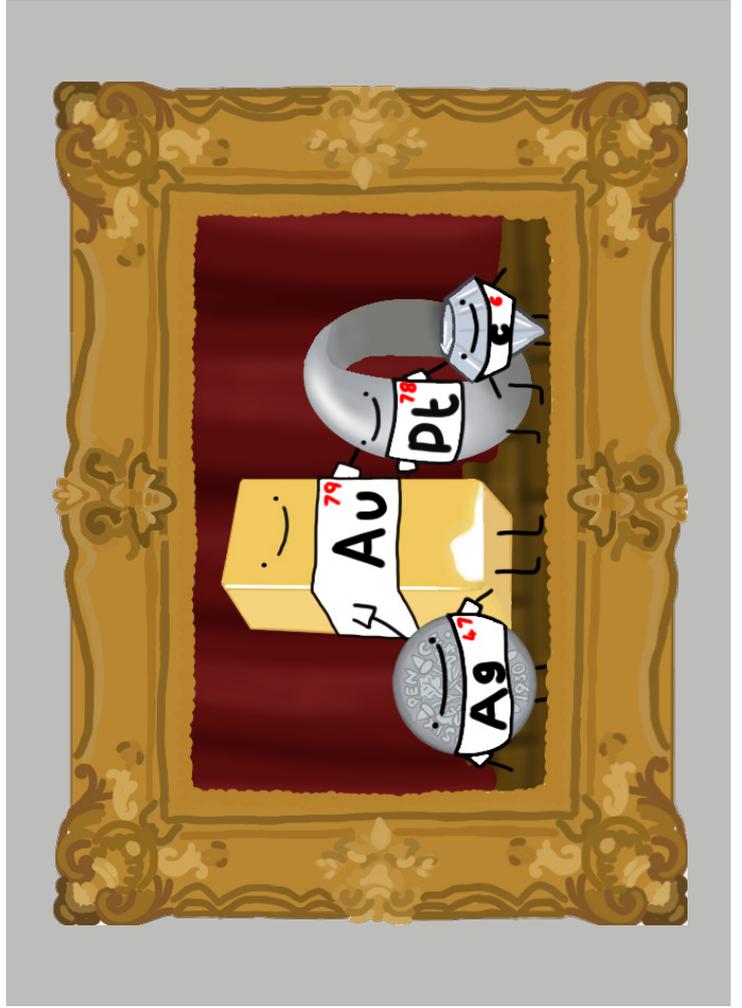
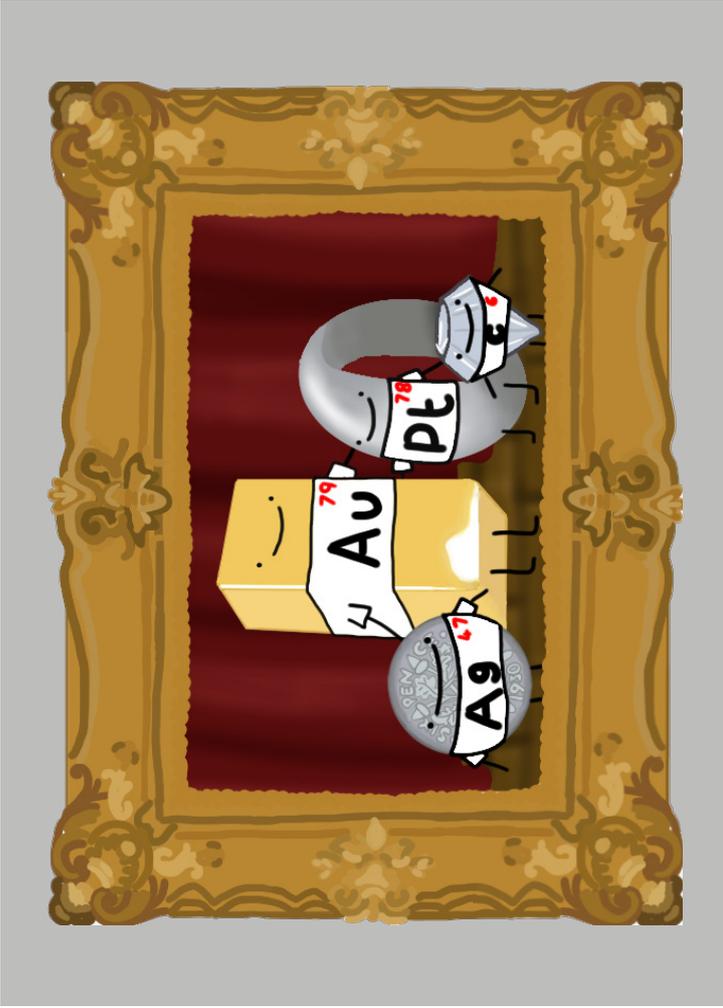
**DISCOVERED BY:** *Paul Emile Lecoq de Boisbaudran (France)*

**DISCOVERED IN:** 1875

**HOST MINERAL:** *sphalerite*

**USES:** *electronics, microwave circuits, high-speed switching circuits, infrared circuits, alloys, LEDs, jewellery*





## YTTRIUM

Y

39



YPO<sub>4</sub>

88.91

DISCOVERED BY: Friedrich Wöhler (Sweden)

DISCOVERED IN: 1828

HOST MINERAL: *xenotime*, *eudialyte*, *clays*

USES: LEDs, compact fluorescent lightbulbs, production of electrodes, electrolytes, electronic filters, lasers, superconductors, various medical applications, phosphors

ELEMENTS FOR LIGHTING



## EUROPIUM

Eu

63



Ce(CO<sub>3</sub>)F

151.96

DISCOVERED BY: Paul Émile Lecoq de Boisbaudran (Europe)

DISCOVERED IN: 1890

HOST MINERAL: *monazite*, *bastnäsite*, *xenotime*

USES: red phosphor in mobile phones, TVs and computer monitors, banknote security, fluorescent lamps, quantum memory chips

ELEMENTS FOR LIGHTING



## TUNGSTEN

W

74



FeWO<sub>4</sub>

183.84

DISCOVERED BY: José and Fausto Elhuyar (Spain)

DISCOVERED IN: 1783

HOST MINERAL: *ferberite*, *scheelite*

USES: drill-bits, light bulb filaments, X-ray tubes, electrodes in TIG welding, superalloys, radiation shielding, projectiles, catalysts

ELEMENTS FOR LIGHTING



## NEON

Ne

10



20.17

DISCOVERED BY: Sir William Ramsay, Morris W. Travers (UK)

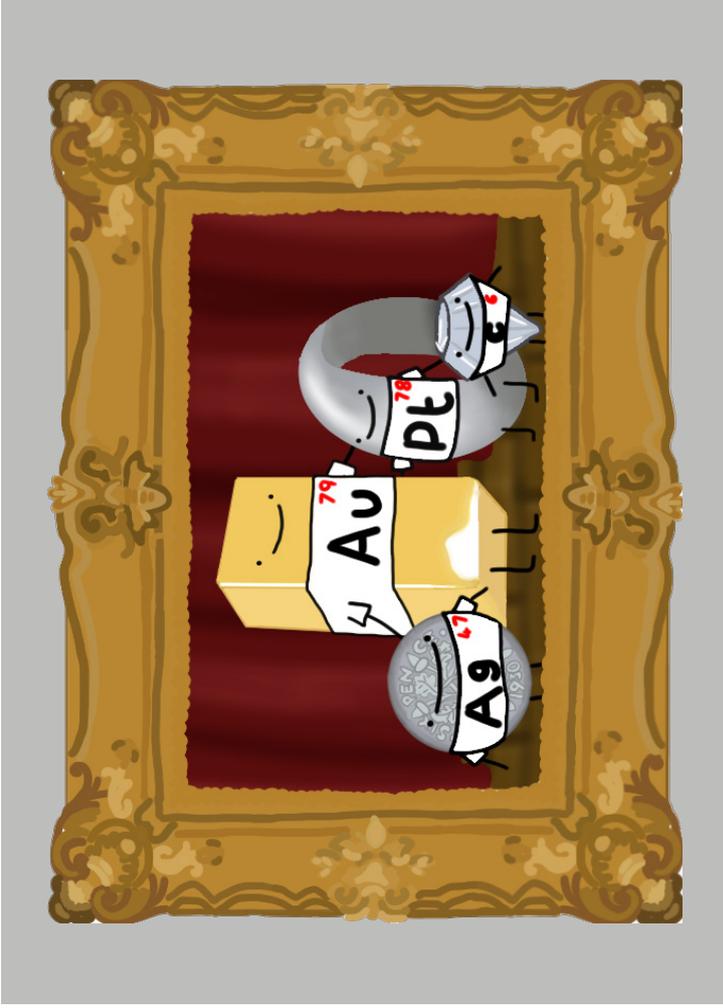
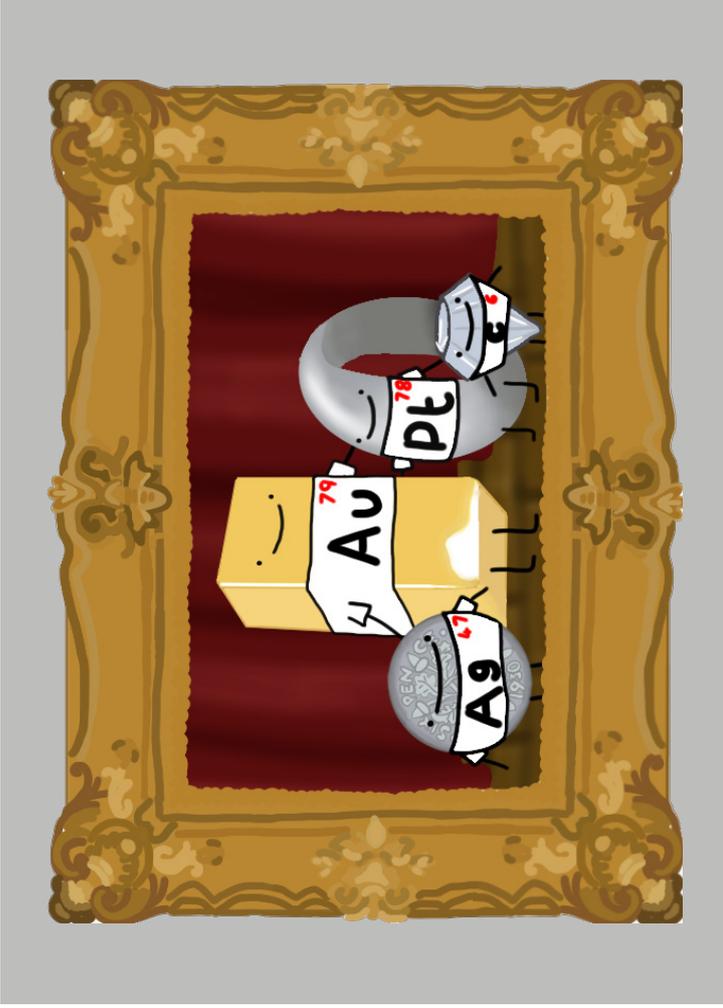
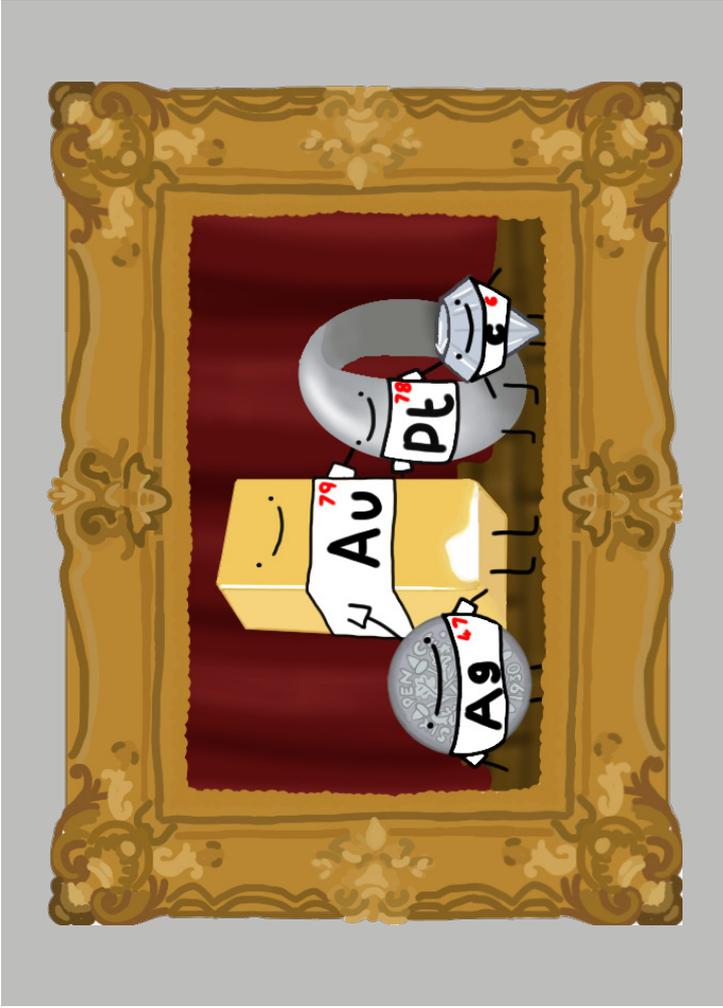
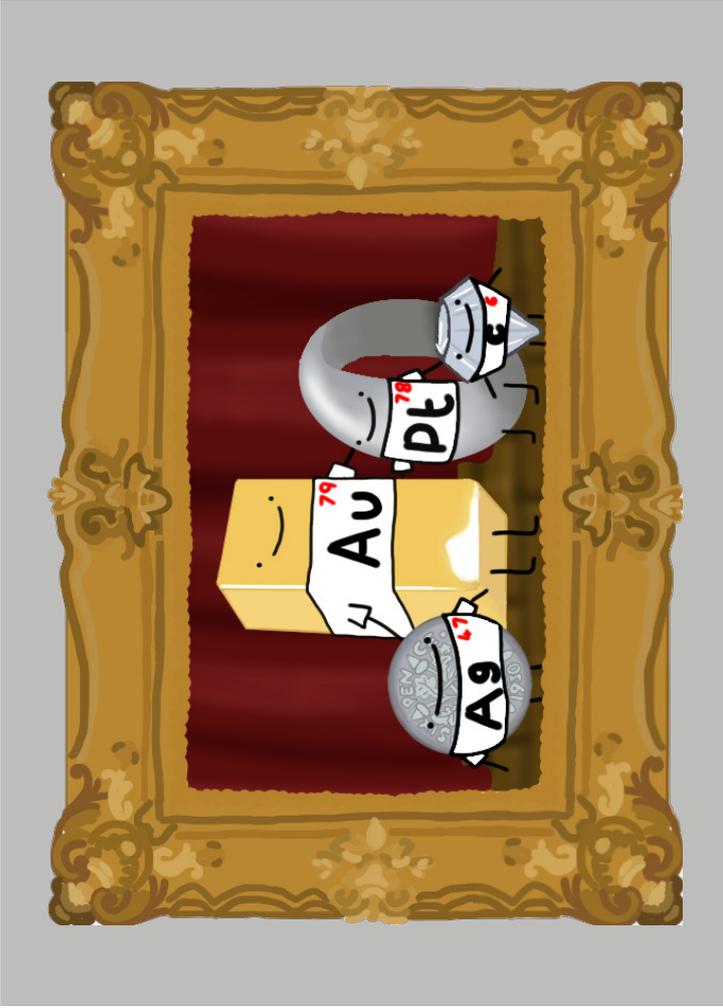
DISCOVERED IN: 1898

HOST MINERAL: *air* (fraction of)

USES: signs (bright reddish-orange light), vacuum tubes, high-voltage indicators, wave meter tubes, television tubes, lasers

ELEMENTS FOR LIGHTING





## CERIUM

Ce

58



$Ce(CO_3)F$

140.12

**DISCOVERED BY:** Carl Gustaf Mosander (Sweden)

**DISCOVERED IN:** 1839

**HOST MINERAL:** *bastnäsité*, *monazite*

**USES:** glass polishing, catalytic converters

ELEMENTS FOR CATALYTIC CONVERTERS



## RHODIUM

Rh

45



$PtAs_2$

102.91

**DISCOVERED BY:** William Hyde Wollaston (UK)

**DISCOVERED IN:** 1803

**HOST MINERAL:** *sperrylite*

**USES:** catalytic converters, electrical contacts, rhodium plating in components for optical instruments

ELEMENTS FOR CATALYTIC CONVERTERS



## LANTHANUM

La

57



$Ce(PO_4)$

138.91

**DISCOVERED BY:** Carl Gustaf Mosander (Sweden)

**DISCOVERED IN:** 1923

**HOST MINERAL:** *monazite*, *bastnäsité*

**USES:** batteries, hydrogen storage alloys, catalytic converters, studio lights/projectors, ignition elements, arc welding electrodes

ELEMENTS FOR CATALYTIC CONVERTERS



## PALLADIUM

Pd

46



$PtAs_2$

106.42

**DISCOVERED BY:** William Hyde Wollaston (UK)

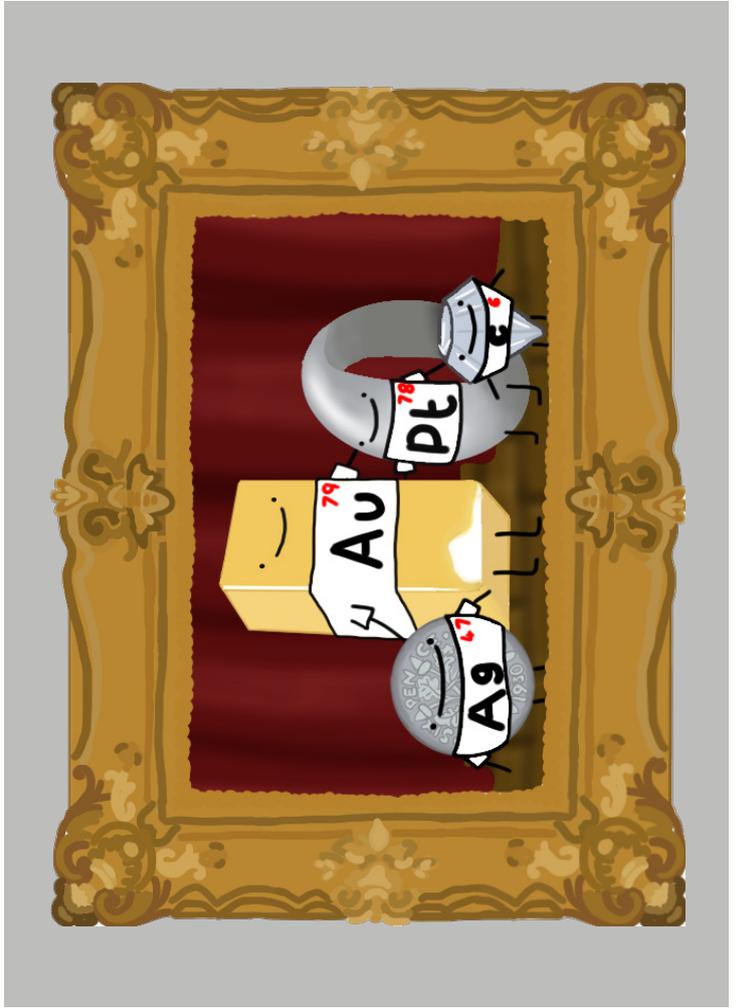
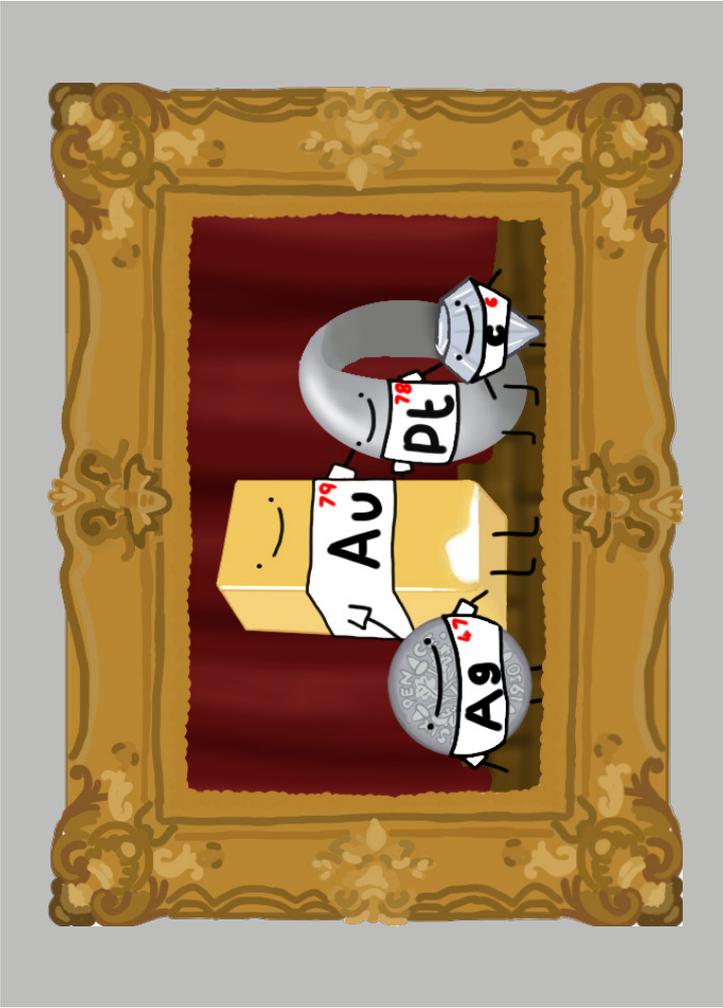
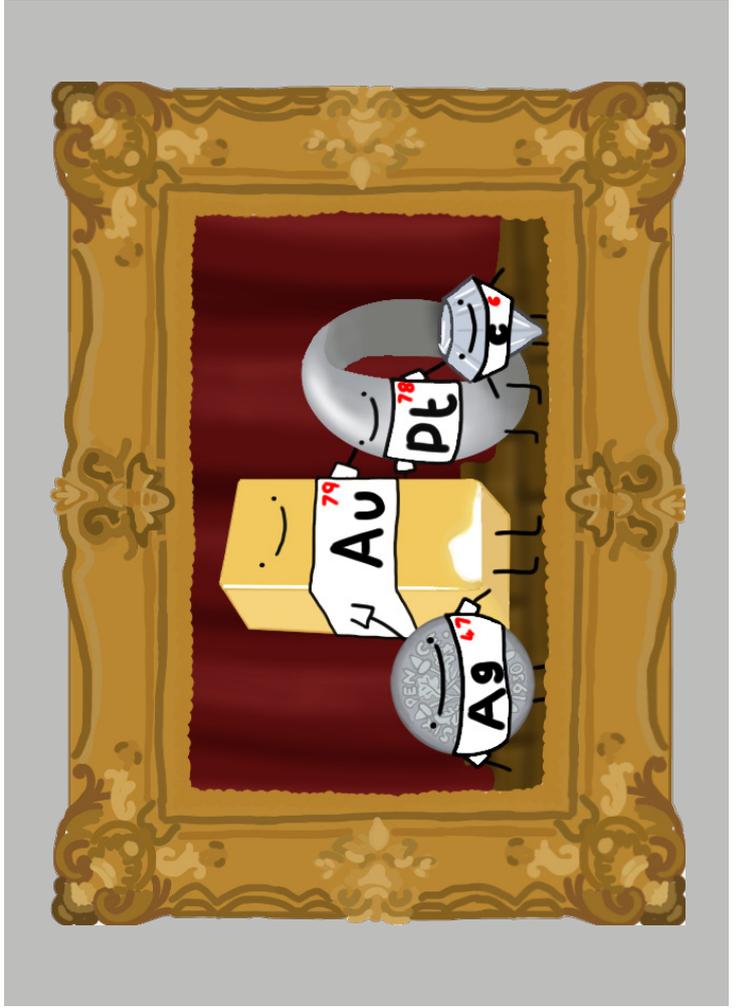
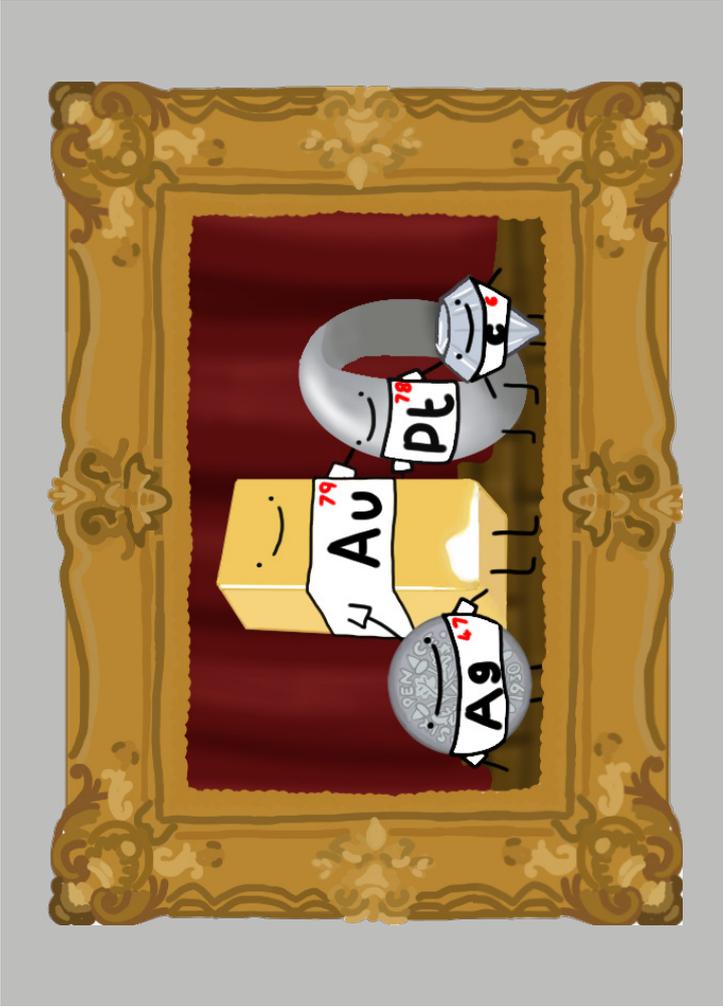
**DISCOVERED IN:** 1803

**HOST MINERAL:** *sperrylite*

**USES:** catalytic converters, electronics, technology, hydrogen storage, dentistry, jewellery, photography

ELEMENTS FOR CATALYTIC CONVERTERS





## PRASEODYMIUM

Pr

59



$Ce(CO_3)F$

140.91

**DISCOVERED BY:** Carl Auer von Welsbach (Sweden)

**DISCOVERED IN:** 1885

**HOST MINERAL:** *bastnäsite*, *monazite*

**USES:** magnets, colouring glass (green/yellow), yellow light filter

RARE EARTHS FOR MAGNETS



## NEODYMIUM

Nd

60



$Ce(PO_4)$

144.24

**DISCOVERED BY:** Carl Auer von Welsbach (Austria)

**DISCOVERED IN:** 1886

**HOST MINERAL:** *monazite*, *bastnäsite*

**USES:** magnets in hybrid/electric car motors, wind turbines, glass dyes, lasers

RARE EARTHS FOR MAGNETS



## SAMARIUM

Sm

62



$Ce(CO_3)F$

150.36

**DISCOVERED BY:** Paul Émile Lecoq de Boisbaudran (French)

**DISCOVERED IN:** 1879

**HOST MINERAL:** *monazite*, *bastnäsite*

**USES:** motorsport hybrid motors, magnets in commercial aircraft wing controllers, cancer fighting drugs, control rods of nuclear reactors, X-ray lasers

RARE EARTHS FOR MAGNETS



## DYSPROSIUM

Dy

66



$YPO_4$

162.50

**DISCOVERED BY:** Paul Émile Lecoq de Boisbaudran (France)

**DISCOVERED IN:** 1878

**HOST MINERAL:** *xenotime*, clays

**USES:** wind turbines, electric and hybrid car motors, control rods in nuclear reactors, data storage applications (high magnetic susceptibility), component of Terfenol-D

RARE EARTHS FOR MAGNETS



