OUR PRESENT KNOWLEDGE OF CANAL RAYS: A DETAILED BIBLIOGRAPHY

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Introduction

My object in compiling the following collection and correlation of the chief facts and theories regarding canal rays, as published to date by various experimenters, is two-fold.

First, it is hoped that the paper will prove valuable in itself. It aims to be complete, to include all important phenomena discovered, and to give exact references where details and methods may be found. It should be an accurate map of the boundaries of knowledge in this domain of Physics, and should prove suggestive to research by indicating unexplored regions, and helpful to theorists by containing the important phenomena to be explained and the suggestions put forward by others.

Second, it is hoped that the paper may illustrate the general method well enough to commend its use by others in connection with other branches of Physics, that these, too, may be mapped. Every physicist would value greatly such a boiling down of the literature in his field.

In making the compilation, the articles were read as far as possible in chronological order, notes of facts reported being made on cards and slipped into a card index under suitable heads. When all the articles had been read, it was a simple matter to put together the facts thus garnered. The method is perfectly flexible; results reported later can easily be incorporated.

I shall be under deep obligation to any who will let me know of such mistakes or omissions as they may find in the following article.

I am indebted to the authorities of Clark University for the privilege of using their fine Physical Library.

The subjects included in the present paper are arranged under the following heads:

I. BIBLIOGRAPHY.

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    Intensity distribution in Doppler effect.
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3. Chemical effects.
4. Secondary emission of negative rays.

I. BIBLIOGRAPHY.

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Sg3	" "	Wien. Ber. 116, 129.	1907.
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Partial List of Articles on Positive Rays Other than Canal Rays.

Positive Rays in General: GR(726-9, 380-5); also Ann. Phys. 25, 882.

Cathode Afflux: V1; V2; V3; Wh2.

K_1-Rays: G1(698, 47); G3(207); G6(229, 373).

S_1-Rays: G2; G6(230, 374); Tm7(363); Kz1; Tm8(664).

Photo-Electric Positive Rays: H. Dember, Ann. Phys. 26, 403-8.

J. J. Thomson Rays: J. J. Thomson, Proc. Roy. Inst. 1897; Tm7(362); Tm8(658).
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E. Gehrcke and O. Reichenheim	Verh. Deutsch. Phys. Ges. 9, 593-7.
E. Goldstein	Verh. Deutsch. Phys. Ges. 9. 598-615.
A. Bestelmeyer and S. Marsh	Verh. Deutsch. Phys. Ges. 9, 758-63.
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II. GENERAL DESCRIPTION.

When a discharge is passed through an exhausted tube divided into two compartments by a perforated metal cathode, luminous bundles of rays appear, extending from the holes in the cathode back away from the anode. These are the canal rays, discovered and named by Goldstein—G1(692,39). Similar rays may be obtained with other arrangements of the cathode, but the rays obtained under the simplest conditions, *i. e.,* when the two compartments communicate only through the perforations in the cathode, alone will be considered in what follows.

The rays move in straight lines except in a magnetic or in an electric field. They excite glass and some other substances placed in their path to fluoresce temporarily, thus rendering the place where they strike them visible. They consist for the most part of positively charged particles of matter, with a mass not less than the hydrogen atom. With these preliminary remarks, we proceed to give a summary of their properties as determined so far by experimental research.

Several authors have suggested changing the name from canal rays (Kanalstrahlen) to anode or positive rays—W8(660), Ew3(300), Tm3(561). By "canal rays" as used here is meant a specific form of positive rays.

For brief general discussion of canal rays, see the following: S1; Tm1; Sm4; S4; Wly1; Ew3; And1; S17; Tm4; Tm5; Mn1; GR(726-9); of which the most complete is Ew3. For photo of rays see Prt1 Taf. VII, f14.

III. EXPERIMENTAL RESULTS.

1. APPARATUS.

Illustrations of Discharge Tubes.

Original tube: G1f1; Sm4f49.
Simple tubes: G1ff2 and 3; Bg1f1; WSff1 and 2; W1f2; W3f3; Ew1ff1 and 2; Bo1f1; G3f1; S13f1; Hl2ff5, 6; SHf1; Tm7f12; Mn1f17.
To show charge: Prn1ff1 and 2; V1f6; WSff1, 2, 3 and 4; Ln2ff1, 2; Au1f1; Au2f1; Tm8f5.
To show magnetic deflection: W2f1; W3f4; W5f7; S1f119; W9ff1 and 2; S4ff224 and 225; Tm3f2; Tm8ff1, 2 and 6.
To show electrostatic effects: V3f2; W5ff2, 5, 6 and 7; W6f1; W9ff1 and 2; S13f8; Tm3f2; Tm7f2.
To show fluorescence: Ar1f3; W7f1; Sm2ff1 and 2.
To show secondary emission: Tm2f1; F1ff1 and 2; Au2ff1, 2, 3 and 4; F2f1.

To show ionization: WSff2, 3, 4 and 5.
To show mechanical action: Sw1ff1 and 3.
To measure energy radiated: W11(420).
With alkaline gases: SSff1 and 2.
For very slow rays: S2f1; cf.Wh3(464), Ew3(308).

Suggestions for Obtaining the Canal Rays.

To obtain "Pure" Canal Rays, that is, to prevent cathode rays from "striking back," thus obscuring the canal rays:

1. Perforations in cathode must not be too large. The lower the gas pressure and the thicker the cathode, the larger they may be: G1(697,45); G3(205); Ew3(298). With extreme vacuum, however, cathode rays may appear: W1(170); W3(446).
2. Cathode rays may be bent aside with a weak magnet: G3(206); W5(523,245). They may be distinguished from canal rays by their magnetic or electrostatic deflection or by their charge: W5(523, 245); or by fluorescence excited: G4(11, 101).

To obtain "Slow" Canal Rays, even with high vacuum:

1. An alloy of Na and K, or Ca may be used on cathode: Wh3(464); Ew3(307); Tm3(562).
2. Gas may be ionized by some other agent: S2(585); Wh3(464); Ew3(308).

Fluorescent Screen; a willemite screen is best: Tm3(562).

Pure Gas filling is necessary for some experiments. For precautions and devices used see the following:

H_2. W4(423); W5(525, 255); W6(591, Hittorf); SH(93); F1(154); S13(28,407); S19(400); Ps2(248).
O_2. W4(423); W5(525, 256); W8(661); SH(93); Ps3(261).
He. Rau1(422); Tm3(568).
Hg. W5(525, 255); S19(400).

2. COLOR OF THE BUNDLES OF RAYS.

In N or Air. Apparently bright chamois yellow: G1(692, 696, 39, 44); G3(205). Due to diffuse secondary rays: G2(133); G6(229).
Really bluish: Bg1(695); G2(133); G6(229); Kn3(37).
In O_2. Yellow-pink: G1(696, 44). Turns bluish as potential rises: Ps4(999);
In H_2. Rosy: G1(696, 44). Color very sensitive to impurities in gas, is red for pure H: S13(28, 407).
In H_2 and Na vapor. Brilliant sodium yellow: SS(459).
In H_2 and K vapor. Beautiful violet like potassium Bunsen flame: SS(460).
In CO_2. Greenish gray, white: G1(696, 44).
In N_2O. Momentarily gray, becomes blue in 5 sec.: Kn3(37).
In illuminating gas. Gray: Kn3(37).

In General.—Color is the same as that of first cathode layer: G1(696, 44).
Color is independent of the material of cathode: G1(697, 45).
Color depends to some extent on velocity: S10(254); S23(811).

3. PROPAGATION OF THE CANAL RAYS.

- PROPAGATION IS RECTILINEAR except in a magnetic or electrostatic field: G1(694, 41); Sm4(109). Any obstacle in their path casts a sharp shadow on a screen: G1(698, 46).
- DIRECTION OF PROPAGATION.
  - Relation to Cathode.
    - Plane cathode: G1(694,41); Ew3(299).
      - Each bundle slightly divergent: V3(15); Tm3(1017).
      - Axes of the various bundles converge slightly toward a central axis: W5(469); G5(70); S13(29, 408); G6(236).
        - Convergence increases with vacuum, bundles may cross.
        - Convergence greatest for circle of holes farthest from the center.
    - Front surface of cathode sufficiently concave.
      - Axes of various bundles may be parallel or diverge from a central axis: G1(695, 43); S13f3b.
    - Front surface convex. Bundles converge and may cross: S13f3a.
    - In general:
      - Direction is approximately normal to the front surface of cathode: Wh2(424); G3(205).
      - Direction is independent of shape of back surface, that is, the surface turned away from the anode: G1(695, 43).
      - Direction is independent of the obliquity of the canals, but intensity may be decreased by rays striking the sides: G1(695, 43).
  - Relation to Cathode Afflux and cathode rays.
    - Apparently the rays are the prolongation through the cathode, of the cathode afflux, both always having the same direction: V1; Wh2(423); V3(15). By deflecting the cathode afflux the canal ray bundles are deflected. Relation to cathode rays only apparent: G1(695, 43); G6(236).
    - Canal rays come from those holes alone which are covered by the first cathode layer: G1(695, 43); Wh2(423)f1; G5(70); G6(236).
- DISPERSION, due to collision with gas molecules.
  - Dispersion greater the larger the molecules: SH(96), least in H_2: S1(346), greater in Hg vapor: SH(96).
  - Little dispersion for high discharge potentials: S16(81).
  - Diffuse rays produced: G6(239); Tm7(359).
- ABSORPTION OF THE RAYS.
  - By gas.
    - Independent of the material of the cathode (Al, Fe, Pt): Ew1(182).
    - Decreases as velocity increases, pressure being constant: Ln2(196).
    - With constant velocity, the maximum distance penetrated by the rays as measured with an electrode, depends merely on the mean free path of the gas molecules, at a given pressure being greater in H_2 than in O_2, in O_2 than in CO_2: Ew1(182, 198); Ew3(309); S4(606); Ln2(196); W11(437).
    - Also shown in connection with the Doppler effect: Ew3(312).

ABSORPTION OF THE RAYS.

- By thin film of grease.
    - Thin film on electrode reduced charge received 95%. After polishing electrode with flannel, only 50% penetrated: Au2(314).
    - Length of rays increases with decreasing pressure; visible rays may be over 50 cm. long: G1(695, 43); Sm4(109).

REFLECTION ON STRIKING AN OBSTACLE.

- Diffuse: Au2(318).
- Per cent reflected is a function of the discharge potential, reaching a maximum at a low potential: F1(156).
    - At 2,500 volts, more than 10% are reflected from Pt, Ag, or Cu: F1(155).
    - At 600 volts, about 50% are reflected from Pt, Ag, or Cu: F1(156).
- Reflection on glass wall produces thick bright layer when near enough to cathode: Rau1(421).
    - Shown by Doppler effect in spectrum of light received by a slit at the end of tube: HK(566); S13(41, 423).
    - 20 to 35% of H rays reflected: S13(41, 423).

4. FLUORESCENCE EXCITED.

ON GLASS WALL.

- In air.
    - Color shows great variations, even with same glass: W5(524, 252).
        - Green, yellow, reddish yellow, and salmon observed: G1(697,45); G3(211); Ar1(326); W2(10); W3(447); V3(15); G4; W5(524, 252).
            - Differences due to variations in gas filling: W5(524, 252).
        - Color differs for deflectable and non-deflectable rays.
            - Deflectable excite bright green fluorescence; non-deflectable, a weak yellow brown fluorescence: W4(432, 435); W6(589); W9(675); Sm4(111); S4(649).
- In helium. Sodium light and green fluorescence: Rau1(421).
    - Deflected fluorescence blue: Rau1(422).
- In hydrogen. With pure H, fluorescence is pure green: W5(525, 255); W6(590); S4(649); Rau1(421).
    - With impure H, undeflected part is yellowish: W5(525, 255).
    - With potassium glass, fluorescence is weak blue: W5(525, 256).
- In mercury vapor. Brownish or salmon red, no green: W5(525, 255); W6(590); S4(649).
        - White?: SH(96).
- In nitrogen. Sodium light persists in spite of all efforts to get rid of oxygen: Rau1(421).
    - Glass wall previously exposed to cathode rays, at first shows no sodium light: Rau1(422).
- In oxygen. Brown fluorescence, no green: W5(525, 256); W6(590); S4(649).
    - Sodium light alone appears after careful drying: Rau1(421).
    - No fluorescence with potassium glass: W5(525, 256).

In general. Weak effect compared with that of cathode rays: Ew3(302).
  Temporary effect, soon dying down, but may be revived by heating: Ar1(326).
  Color depends on gas filling, very sensitive to impurities: W5(524, 253); W6(589). Also depends on glass: W5(525, 256).
    Differences persist even for very low pressures, hence are not due to differences of absorption: W6(590).
  Spectrum is always a line spectrum: Ew3(302).
  Strongest fluorescence in the case of H: W4(435), cf. G3(210).
  Sodium light appears inside of glass wall and is easily distinguishable from cathode ray fluorescence: G4; V3(15); Ew3(302).

ON METALS AND METALLIC SALTS.

Cobalt, Manganese, Mercury, Nickel, and Thallium Salts show no fluorescence: Ar1(326); Sm2(706).
Solid solutions: See Ar1(326); Sm2(706, 708).
Aluminum. Polished metal shows no fluorescence: W7.
  Oxide. Pure Al_2O_3 does not fluoresce: Sm3(625).
    One part in 10,000 of chrome oxide causes bright red fluorescence: Sm3(625); Ew3(304). A trace of CuO causes weak green fluorescence, which becomes bluish and then blue as more CuO is added: Sm3(626); Cf. W7; S4(649).
Cadmium salts show yellow fluorescence: Ar1(326); Sm2(706).
  Oxide. Weak greenish fluorescence in H_2 or O_2: W7; S4(649).
Calcium salts. White fluorescence: Ar1(326). Bluish; Sm2(706).
Caesium salts show bright blue fluorescence: Tr1(142).
Copper oxide. No fluorescence in O_2 or H_2: W7.
Iron salts. No fluorescence: Ar1(326); Sm2(706).
  Oxide. No fluorescence: W7.
Lithium. Salts show weak red fluorescence: Ar1(326); G6(229); Tr1(141); Tm3(1017). Chloride becomes black in H_2: Tr1(141).
Magnesium. Salts show green fluorescence, line spectrum: G6(229).
  Oxide obtained by burning Mg shows red fluorescence in O_2 or H_2: W7; S4(649).
    Fluorescence probably due to an oxide impurity held in solid solution: Sm3(633).
Potassium. Pure metal shows no fluorescence: Tm3(1017).
Rubidium salts show red and blue fluorescence: Tr1(142).
Sodium. Pure metal shows no fluorescence: Tm2(214); Tm3(1017).
  Sodium glass. Gold yellow fluorescence, D-line: G4; G6(229).
    " oxide. Greenish yellow: Tm2(214).
    " salts. Red yellow, D-line, no noticeable discoloration of salts: Ar1(326); Sm2(705).
Strontium salts. Rose-white fluorescence: Ar1(326).
Zinc. Salts show green fluorescence: Ar1(326).
  Willemite dusted on glass fluoresces brightly, especially in H_2: Tm3(562, 570).

Zinc oxide.

1. When prepared by burning thoroughly in O_2, it showed an intense green fluorescence: W6(590); Tf1(613); S4(649).

Oxide became coffee-colored and sticky: Tf1(614).

Oxide permanently discolored yellow during fluorescence: W6(590); W7.

White color and power to fluoresce restored by heating: Tf1(616).

Oxygen is released during the fluorescence: W6(590); Tf1(613).

No chemical change occurs large enough to detect by balance: Tf1(614).

Oxide can be discolored and power to fluoresce be removed by intense pressure: Tf1(615).

2. Chemically precipitated oxide shows little or no fluorescence: W6(590); Tf1(616).

Oxide may be purified chemically until it will no longer fluoresce: Sm3(623, 628).

Minute traces of cadmium oxide caused it to show an intense green fluorescence: Sm3(628).

Flakes or smoke from burned Zn show no fluorescence unless heated: S3(390).

Explanation offered is that pure ZnO does not fluoresce except when it contains some other oxide in solid solution: Sm3(623, 628); cf. Tf2.

METALLIC OXIDES IN GENERAL.

Pure oxides, chemically obtained, do not fluoresce: Sm2(707); Sm3(625, 628, 633); Ew3(303).

Oxides obtained by burning the metal may fluoresce: Ew3(303).

Oxides containing other oxides in solid solution may fluoresce: Sm2(707); Sm3(625, 628, 633).

Fluorescence the same in either H_2 or O_2: Ew3(303).

FLUORESCENCE IN GENERAL. S4(649).

Temporary. All substances soon lose capacity to fluoresce in canal rays: Ar1(326); Sm2(706); W6(590); W7.

Extremely sensitive to minute quantities of impurity: Sm2(710).

Superficial: Ar1(326); Sm2(706).

Spectrum. As fluorescence dies down spectrum bands widen out and finally disappear in a continuous spectrum: Sm2(707, 711).

5. CHARGE CARRIED BY THE RAYS.

RAYS POSITIVELY CHARGED for the most part.

Shown by the direction of the magnetic and electrostatic deflection (see below): Tm1(521); Sm4(110).

Shown by the positive charge received by a Faraday cylinder or electrode struck by the rays, cathode being earthed: Prn1; W1; W3(446); Ew1(175); Bg1(692); W5(524, 251); Ln2(198); W9(671); Au1; F1(153); Pry1.

NOTE.—In order to give the true current carried by the rays, charge received by an electrode must be corrected for two secondary effects elsewhere described, viz:

(1) Reflection of rays from electrode (see § 3), and

(2) Secondary emission of cathode rays excited (see § 9).

Nevertheless, Austin's work seems to be conclusive: Au1.

Failure to consider these effects may account for the following negative results reported: Ar1(327); V1; V3(16); Ln2(180); Bg1(692).

SOME NEGATIVELY CHARGED, as shown by the direction of the magnetic deflection: W5(262); Tm3(568); Tm8(671).

Proportion of negative rays to whole is small: W10(212).

SOME RAYS UNCHARGED for a portion of their path: Tm8(670).

CURRENT CARRIED BY THE RAYS.

Ratio of current flowing to earth from electrode, to total discharge current, determined under varying conditions of pressure and tension, in air, O_2 and H_2: Ew1(176-82), plate I; Ln2(198); cf. Pry(448).

Maximum current measured about 10^{-1} amp.: Ew1, plate I.

No correction for secondary emission: F1(153).

Ratio reaches a maximum about at pressure when cathode ray fluorescence begins: PryI(448).

Undeflected rays also charged in part: W4(434); W9(671, 673).

6. MAGNETIC DEFLECTION.

DIFFICULTY IN OBSERVING EFFECT.

First overcome by W. Wien, in 1898: W2(11); W3(448); W4(423).

Effect a thousand times smaller than in the case of the cathode rays.

Main discharge must be protected from the influence of the strong magnetic field employed: W2(11); W3(448); W4(422); G5(70); W5(523, 244); G6(237); Tm3(563).

Negative results reported: G1(698, 46); Ar1(325); Prt1; V1; V3(15); G3(208).

Suggestions for observing effect: W5(523, 245); Tm3(562).

SENSE OF DEFLECTION, such as to prove the positive charge carried by the rays: W2(12); W3(448); W5(523, 245); Tm3(568).

Part of the rays are deflected in the opposite sense, indicating that part of the rays for a portion of their path are negatively charged: W5(262); Tm3(568).

CHARACTER OF THE DEFLECTION.

Non-uniform, spot drawn out in streak, part undeflected: W2(12); W3(448); W4(431); Rau1(422); Tm3(564), 568).

Diagram of deflection streak in air, also in H_2 shown in Tm3.

Not due to impurity in the gas filling: W4(431).

Deflected fluorescence brighter than undeflected, in H_2: W4(432); W6(589).

May differ in color from undeflected: W4(432); W9(675); Sm4(111); S4(649). Most deflected fluorescence is always green, but becomes very faint if gas is carefully purified of H_2: W10(213).

Deflected beam much less bright than undeflected: W4(432, 435).

MAGNITUDE OF MAXIMUM MAGNETIC DEFLECTION.

Maximum deflection about 2 cm. with field of 500 C. G. S. units, tension 30,000 v., screen at a distance of 7 cm. from cathode: W4(431); W5(561, 263); W8(663).

Originally reported deflection much smaller: W2(12); W3(448).

Independent of gas and also of cathode material. In H_2, however, a larger proportion seem to be deflected nearly the maximum amount: W4(431); W9(674); Tm3(575).

LONG CANAL RAY BEAM. Curious behavior in magnetic field: Pl1(1008).

7. ELECTROSTATIC DEFLECTION.

DIFFICULT TO OBSERVE because gas becomes ionized by the rays, and electric field cannot be maintained: W2(11); W3(447); W4(425).

Effect small; first observed by W. Wien in 1898: W2(10); W3(447).

SENSE OF DEFLECTION same as that of magnetic deflection: W2(11), etc.

CHARACTER. Same as that of magnetic deflection: W5(560, 259); Tm3(564).

MAGNITUDE. With a field of 400 v./cm., discharge potential of 10.000 v., length of plates 5 cm., distance of screen 10 cm., a deflection of about 1 cm. would be obtained: W5(561, 259, 264).

ELECTROSTATIC ACCELERATION OF RAYS.

By applying a field parallel to the rays, the fluorescence can be weakened or brightened according to direction of field: W5(561, 260).

8. SIMULTANEOUS MAGNETIC AND ELECTROSTATIC DEFLECTION.

EXPERIMENT due to W. Wien: W5(561, 261).

Magnetic and electrostatic fields are superposed, and so arranged that they tend to deflect the rays in mutually perpendicular planes. The resultant deflection streak is observed on the glass or willemite screen at the end of the tube.

WITH ORDINARY LOW PRESSURES.

Fairly straight diagonal streak extending from origin, in air, H_2 or pure O_2: W5(561, 263); W6(588); W8(661–3). For diagrams see Tm3(568, 571).

WITH EXTREMELY LOW PRESSURES.

Undeflected spot and negative branch disappear: Tm3(572).

Streak breaks up into two or three patches.

Same two patches for all gases air, H_2, O_2, He, CO_2, Ar, and Ne. He giving, in addition, a third patch: Tm3(573, 575); Tm6(295).

One patch is deflected the amount to be expected if canal rays are singly charged hydrogen atoms.

Second patch corresponds to singly charged hydrogen molecules.

Third patch, obtained under certain conditions with helium, corresponds to singly charged helium molecules: Tm3(571).

Effect not due to presence of H_2 as impurity. Brightness of fluorescence patch measured photometrically and found to be the same whether extreme precautions were taken to eliminate H_2 or not: Tm6(295); Tm7(360); cf. W10(212).

Hydrogen canal rays abundant when no hydrogen ions can be detected in other parts of the tube: Tm8(680).

As pressure increases, patches enlarge, overlap and merge to form the continuous, fairly straight streak: Tm3(574).

9. SECONDARY EMISSION OF NEGATIVE RAYS FROM A METALLIC SURFACE STRUCK BY CANAL RAYS.

INTENSITY OF SECONDARY RADIATION.

Function of the *velocity* of the canal rays, few negative rays for low tensions (600 v.): F1(156); F3(301).

Kinetic energy of canal rays must exceed a certain value: Pry1(448).

Function of the *angle of incidence*.

Much less for normal than for greater angles of incidence in case of Al and brass: F1(153); F2(749); Au2(315); F3(306).

In case of Cu, variation is slight: F1(153); F3(306).

Depends on the *metal struck*.

For high tensions (30,000 to 75,000 v.), the secondary negative current emitted is the following per cent of the canal ray current: Al, 300 per cent; Zn, 170 per cent; Cu and Ag, 100 per cent; Pt, 80 per cent: F1(155). For brass, 6,000 v., 45 per cent: Au2(314).

Measurements complicated by the positive reflection, which for the lower tensions may overbalance the negative emission: F1(155).

Relation to cathode fall.

Metals which used as cathodes have the greatest cathode fall for a given pressure, show the least negative emission when struck by canal rays: Ew3(310).

VELOCITY.

Not very great, since emission is stopped if electrode is charged to a low positive potential: Tm2(213).

Varies considerably among the rays: Au2(318).

AVERAGE VELOCITY, that is, the velocity of most of the rays, measured by deflecting them magnetically through a curved canal, and determining the current received by an electrode at the end as a function of the field strength: F2(749).

Value is 3.2 to 3.5 x 10^8 cm. for Pt or Al: F2(749); F3(301, 304).

Independent of the velocity of canal rays: F2(749).

Independent of the gas (H_2 or air): F2(749).

Independent of the angle of incidence: F2(749).

Independent of the metal struck (Pt or Al): F2(749); F3(301, 304).

Same as that of secondary rays produced by cathode rays striking a metal: Ew3(310).

Distribution of the rays among different velocities shown by curves: F3(303). Varies with gas and with metal: F3(304).

10. CHEMICAL EFFECTS.

REDUCING EFFECT.

In H_2, $HgCl_2$ reduced to Hg_2Cl_2 to some depth, no fluorescence: Sm2(709). $FeCl_3$ reduced to $FeCl_2$: Sm2(710).

Various other metallic compounds reduced: Sm3(622).

In O_2, these reducing effects do not take place: Sm2(710).

Metallic oxides in solid solution are reduced, oxygen being evolved during fluorescence: W6(590); W7; Tf1(613); S4(654).

OXIDIZING EFFECT.

All oxidizable metals are superficially oxidized by the rays: Wh2(425); Sm2(708); S4(654); Sm3(622); Sm4(112).

Cu shows effect better than Cd, Al or Zn.

Oxidization proved by chemical analysis: Sm2(708).

Shaded parts of surface also oxidized as well as parts directly struck by the rays: Sm2(708).

Au, Ag, and Pt show no oxidization in four hours: Sm2(609).

PbO turns brown by formation of PbO_2: Sm2(709).

Hg_2Cl_2 turned black: Sm2(709).

Not a heat effect, red HgI_2 not changed to the yellow iodide: Sm2(708).

DISSOCIATING ACTION.

With acetylene, carbon is deposited on walls: Kn3(35).

No deposit where rays strike walls: Kn3(35).

N_2O and CO_2 easily dissociated by the rays: Kn3(37).

Dissociation of H_2 and O_2 may account for apparent chemical effects described above: Sm2(711); Sm3(622); Sm4(113); S4(654); Ew3(304).

Metallic compounds decomposed: V2; V4; Tr1(142); Ar1(327).

ACTION ON SENSITIZED PAPER.

Canal rays affect sensitized papers, rendering them less sensitive to daylight, so that by exposing a canal ray positive to sunlight, it may be changed to a negative: Zn1(38).

Celluloid paper is rendered more reflecting where rays strike: Zn1.

Photographic action slow, long exposure necessary: Prt1.

11. MECHANICAL EFFECTS.

DISINTEGRATION OF METALS struck by the rays: S4(630); Tm2(214).

Too small in amount to weigh: Kl1(871).

Varies for different metals: Al, none; Cu, small; Au and Pt, distinct deposit on walls of tubes; brass disintegrated but no deposit: Kl1(871).

Varies with gas, greater in air than in H_2 in case of Au and Pt.

Not sensitive to traces of impurity in gas: Kl1(872).

PENETRATING POWER.

Canal rays will penetrate only extremely thin thicknesses of metal, paper, or mica: W1; W3(445); V3(15). Metallic compounds decomposed: V2; V4; Tr1(142).

Penetrate deeper in Al than in Cu, a possible explanation of some of the secondary cathode ray emission phenomena: F3(307).

Heating Effect.

Obstacles struck are warmed: V1(1341); Ar1(327); Sw1(393).

Heating of end of tube measured calorimetrically; 10 to 20 per cent of total energy of discharge regained as heat: Ew1(183, 199). Measured bolometrically: W4(425).

Mica mill-wheels rotated, probably a thermal radiation effect: Sw1(393).

12. MISCELLANEOUS EFFECTS.

Charged Electrodes do not appreciably affect rays: V1; V3(15); G3(208).

Bundles Cross without any apparent interference: G1(698, 46).

Ionization of Gas takes place if canal rays have sufficient velocity (500 v.): S13(170, 427).

Second discharge may be passed through part of tube traversed by the rays using only one-fourth the potential otherwise required: WS(470–3).

Effect makes the use of an electrostatic field difficult: W3(447).

Screening Effect. Electric waves are absorbed by a tube traversed by canal rays: WS(470).

13. SPECTRUM OF LIGHT FROM CANAL RAYS.

The light may be received in a collimator pointed in a direction parallel or perpendicular to the rays. In the former case, whatever light is being radiated from the particles forming the rays while they are in motion should show a Doppler effect, since the wave length of the light from the moving particles will be slightly altered by the motion in the line of sight, causing a shift in the position of the lines in the spectrum. There is always besides the "displaced line" the "rest line" with, usually, an "intensity minimum" between: S22(905).

Aluminum Lines show Doppler effect.—λλ 3944, 3962. Intensity weak: S23(822).

In Air. Band spectrum of N appears: G1(692, 39).

In Argon. Doppler effect observed for 20 lines surely; for ten more, probably: D1.

In Carbon Dioxide.

Contains C line λ 4267 and H lines, all very bright. N, Swan, and C bands also present: Kn3(37).

Doppler effect shown by H lines and λ 4267: Kn3(37); S19f2(photo).

λ 4267. Shift of 5Å with 10,000 v.: Kn3(37).

H lines more intense for lower pressures: Kn3(37).

Band spectrum shows no Doppler effect: Kn3(37).

In Helium.

Doppler effect shown by λ 4472 and other lines: S19f1(Rau); D1(589).

Negative results: Rau1(423); Hl2(15, 16).

In Hydrogen.

- Contains main series line spectrum: Wlr1(132); SH(94)f4; S5(894, 462); S9(112, 249).
  - Also $\lambda 4688$: S13(43, 425); S9(112, 249).
  - Also H band spectrum and sometimes metal lines: SH(94)f4; S5(461, 893); S13(43, 425).
  - Line spectrum relatively more intense, the greater the discharge potential: SH(95).
  - Intensity of shorter wave lengths increases faster: S10(253); S21(799). Hence, as potential increases, the intensity maximum in the series shifts to shorter wave lengths: S13(184, 444).
- Doppler effect—see photo S5f1; Ps2, plate III; S20f1; SWff3 and 4.
  - Shown by all lines of line spectrum: S5(462, 894); S13(33, 414); Hl2(12); D1(589); Ps2(250).
  - Cathode fall must exceed 700 v.: S20(64).
  - Rest line sharp, intensity less than that of displaced line: S5(462, 894); S13(183, 443). Intensity closely related to that of band spectrum: S13(173, 43).
  - Intensity of displaced line not a function of pressure: S13(34, 415); not related to stationary intensity: S13(175, 434).
  - Ratio of intensities of displaced lines of different wave length in the same series is a function of the cathode fall: SSt(924).
  - Intensity distribution, or cross section of intensity is similar for all lines of series: Ps2(250); Ps4(997); cf. S13(182, 442); S21(799); SSt(924-5). For diagrams of intensity distribution see: HK(565); S13f5; Ps2(250).
  - Shift as a function of wave length.
    - $\Delta\lambda/\lambda$ constant for maximum displacement of all lines showing effect: S5(462, 894); S9(112, 249); S13(33, 414).
      - Constant for maximum intensity of displaced line: Ps2(251); Ps4(997); cf. S21(799).
  - Shift as a function of discharge potential. See Fig. 61.
    - Maximum shift proportional to the square root of potential approximately: S5(462).
    - Shift of about 5Å for velocity of 3×10^7cm.: Hl2(12); S13(33, 414).
    - Shift the same for light from all parts of rays: SW(745).
    - Second displaced line appears with low velocities, 800 to 2.000 v.: Ps2(252 and plate III).
      - Sharp for the lower velocities, widening for higher.
- Band spectrum shows no Doppler effect: S5(463, 894); S13(43, 425).

In Sodium Vapor.

- Difficulties of experiment: SS(457); S5(463). Only one plate of a number, intense enough.
- Contains main and first and second sub-series of line spectrum: S5(463).
- Doppler effect observed in case of two doublets of first series, a fine, displaced line, shift not measurable: SS(460); S5(463).

IN MERCURY VAPOR.
- Contains first and second sub-series of triplets: S9(112, 250).
  - Also λλ 4358, 4047, and 2537: SHK(463, 467).
- Doppler effect. Unquestionably observed for 12 Hg lines: S18(233); S20f3.
  - λ 5461. Small displacement: S5(463).
    - Observed by Paschen: S20(65). No displacement observed with echelon, tension 60,000 v.: Hl1; Hl2(13).
  - λλ 4347, 4078. Distinctly observed only with high voltages, 45,000 to 60,000 v.: SHK(468); S13(180, 439).
    - Shift points to trebly charged atom as carrier: SHK(468).
  - λ 2537. Shift points to singly charged atom as carrier: SHK(467).
  - Lines of 1st and 2nd series of triplets: S5(463); SHK(468); S20(64).
    - Same modified shift, $\Delta\lambda/\lambda$, for all components of a triplet and for all triplets of both series: S9(112, 250); SHK(466); S13(181, 440).
    - Shift points to doubly charged atom as carrier: SHK(465).
  - Displaced intensity relatively very weak, greater for higher velocities and for shorter wave lengths: S13(176, 434); S20(63).
  - Effect independent of the presence of H_2: S20(65).
  - Discussion of Hull's negative results: S18; Hl3; S20; Hl4.

IN NITROGEN. See SHff2 and 3.
- Contains both the band and series line spectra of N, but band spectra subside as potential increases: Hr3(568); SH(95).
- Doppler effect.
  - λ 3995. Shift distinctly observed: S5(463); SH(94); Hr3(569) (photo).
    - Intensity minimum well defined: S10(256).
      - Width varies but slightly with cathode fall: Hr3(569).
    - Maximum shift points to singly charged N atom as carrier: Hr3(569).
  - λλ 5006/03, 4643/31/22/14/07/01, 4530, etc., all show shift similar in appearance and amount to λ 3995: Hr3(569).
  - Band spectra show no Doppler effect: S5(463); Hr3(568).

IN OXYGEN.
- Contains:
  - (1) elementary line or spark spectrum of O: G1(696, 44); Wlr1; Ps3(261); Ps4(999); S23(814).
  - (2) series of triplets: Ps3(261). Become weaker with higher discharge potentials: **Ps4(999).**
  - (3) traces of bands: Wlr1.
- Doppler effect shown by elementary line spectrum: Ps3(263); Ps4(998).
  - All lines in question show same displacement and appearance: Ps3(263); S23(814).
- Doppler effect for triplets even with high velocities doubtful: Sg3(129); Ps3(263); Ps4(998); S21(804); S23(819).
  - Intensity very weak, shift not measurable: S23(821).

IN POTASSIUM VAPOR.

Difficulty of experiment: SS(457); S5(463).

Contains main and first and second sub-series of line spectrum: S5(463).

Doppler effect observed in case of doublet, $\lambda\lambda$ 4044–47 distinctly: S5(463); SS(460); S9(112, 250). No intensity minimum.

Shift corresponds to singly charged potassium atom as carrier: S5(463); S9(112, 250).

IN ILLUMINATING GAS.

Contains H lines, C line λ 4267, N line λ 3995, all very bright, also N bands and Swan bands which are rather weak: Kn3(37).

Doppler effect shown by all lines, but by no bands: Kn3(37).

IN ACETYLENE.

Contains H lines and C line λ 4267, all bright. N, C, and Swan bands are visible also: Kn3(36).

Doppler effect shown by all lines but by no bands: Kn3(36).

λ 4267 shows intensity minimum, shift points to singly charged C atom as carrier: Kn3(36).

SPECTRUM IN GENERAL.

Spectrum is a part of that of gas in tube, same part as that of light from first cathode layer, that is the series line spectrum: G1(696, 44); Wlr1(132).

May contain lines of metal forming cathode: SH(93).

May contain band spectrum of gas besides line spectrum, but the latter is relatively more intense the greater the discharge potential: SH(95).

DOPPLER EFFECT IN GENERAL. For summary see S23(828).

Conditions to be satisfied to obtain effect: S18(231); S19(399).

Measurements only semi-quantitative because of inestimable errors: S13(33, 179, 413, 438).

Shown by series line spectra of H, N, O, Na, K, and Hg: S5(461, 893), perhaps also by O triplets: Sg3(129); S23(821); Ps4(998). Also by spectrum of He: S19(401) and of Al: S23(822).

Not observed for any band spectrum.

Amount of shift serves to distinguish light from singly, doubly, and trebly charged atoms: S5(464, 894).

All lines of same series show same modified shift, $\Delta\lambda/\lambda$, hence have same carrier: S13(33, 414).

Intensity minimum in general separates displaced from rest line: S10(252, 256); S13(31, 412, 179, 438); S19(399).

Width varies with gas and in any series varies with λ (?): S21(799); Ps2(250).

Less distinct the greater the pressure: Ew3(312).

Velocity corresponding to width of intensity minimum must be exceeded by the canal rays or no displaced line will be obtained: S13(180, 439); S18(232); S19(399); S20(64).

Minimum velocity varies for different gases and for different lines in any series (?): S21(799).

Intensity of displaced line obeys different laws from that of rest line increasing with the velocity of the rays: S18(232).

- Displaced intensity varies with gas and, in any series, with λ: S13(176, 434); S20(63).
- Ratio of stationary to displaced intensity same on any one spectrogram for all lines of one series: S13(182, 441).
- Stationary intensity appears to vary in step with that of band spectrum, increasing with the pressure: S13(175, 434).

Absence of Doppler effect in some cases not well understood: Hl4(119).

Shift of Lines Toward Red, observed with collimator perpendicular to rays.

- Definitely observed on all spectrograms taken, determined by measuring the position of lines in question with reference to certain band lines, most probably unshifted: S7; S8(107); S13(191, 452).
- Amount 0.7 Å for H_β with 8,000 v.: S13(194, 453).
- No shift observed by Hull for H or Hg lines: Hl1; Hl2(19).
- Apparent shift may be due to error in setting collimator and may be the Doppler effect: S13(189, 450).

Broadening of Lines observed with collimator perpendicular to rays.

- H lines greatly broadened, most just behind cathode: Hl1; Hl2(19).
  - Broadening increases with velocity, shorter wave lengths broaden more rapidly: S7; S8(107); S13(190, 451).
    - Also with pressure: S(42, 423).
  - Partly a Doppler effect: S13(191, 452).
  - Less than Doppler effect in the ratio, velocity of rays to that of light: S8(109).
- Hg lines show slight broadening: Hl1.
- He lines show no broadening: Hl2(19).

14. PARTIAL POLARIZATION OF LIGHT.

Slight effect reported by Stark in case of H lines, vibrations parallel to rays being more intense than those perpendicular to their direction, difference very small and difficult to observe: S7; S8(105, 106); S18(230).

No polarization as great as one-half per cent of light was detected by Hull, using optical glass window and very sensitive Nicol prism and Savart plate: Hl1; Hl2(17); Hl3(234).

IV. MATHEMATICAL THEORY.

1. NOTATION.

c = velocity of light.
e = charge on each particle.
E = energy of n particles.
F = electrostatic field strength.
H = magnetic field strength.
l = distance from cathode to screen.
m = mass of each particle.
n = number of particles.
$q = ne$ = charge on n particles.
ρ = radius of curvature of path in magnetic field.
v = velocity of particles.
V = cathode fall.
x = *electrostatic deflection* on screen.
y = *magnetic deflection* on screen.
$\Delta\lambda_n$ = shift of line λ_n in Ångstrom units or tenth-meters.

$A = \frac{1}{2} F\,(l^2 - b^2)$
$B = \frac{1}{2}\, l^2 H.$

2. EQUATIONS.

(1) $\frac{e}{m} = \frac{v^2}{2V}$; W4(431); S5(464, 894); W5(560, 258); Ew3(309).

Kinetic energy of rays:

(2) $E = \frac{1}{2}\, nmv^2$.

(3) $E = \frac{v^2qm}{2e}$; from definition of q.

(4) $E = neV$; from (1) and (2).

(5) $E = \alpha^2 a$; where α = some number greater than one.
a = heat, in absolute mechanical units, generated by n particles striking an obstacle.

Velocity of rays:

(1) $v = \sqrt{2V\frac{e}{m}}$.

(6) $v = \alpha\sqrt{2\frac{a}{q}\cdot\frac{e}{m}}$; from (2) and (5): Ew1(184).

(7) $v = \frac{l^2H}{2y}\cdot\frac{e}{m}$: W4(431); W5(561, 261); S4(603).

(8) $v = \frac{4Vy}{l^2H}$; from (7) and (1).

(9) $v = \frac{B}{y}\cdot\frac{e}{m}$; Tm3(565).

(11) $v = H\rho\frac{e}{m}$: Tm3(564).

(12) $v = \sqrt{\frac{F(l^2 - b^2)}{2x}\cdot\frac{e}{m}}$: W5(561, 261); S1(346); Tm3(564).

$$v = \sqrt{\frac{A}{x} \cdot \frac{e}{m}}.$$

(12a) $V = \frac{A}{2x}.$

(13) $v = \frac{F(l^2 - b^2)}{l^2 H} \cdot \frac{y}{x} = \frac{A}{B} \cdot \frac{y}{x}$: Tm3(564); W5(561, 261). [(12) and (7)].

(20) $v = c \frac{\Delta\lambda_n}{\lambda_n}$; S5(459, 464, 893, 894); Ew3(313).

Specific charge, e/m.

(1) $\frac{e}{m} = \frac{v^2}{2V}.$

(6) $\frac{e}{m} = \frac{v^2 q}{2a^2 a}$: Ew1(184). [(2) and (5)].

(7) $\frac{e}{m} = \frac{2yv}{l^2 H}$: W4(431); W5(561, 261); S4(603).

(9) $\frac{e}{m} = \frac{vy}{B}$: Tm3(565).

(10) $\frac{e}{m} = \frac{8y^2 V}{l^4 H^2}$: W4(431); S1(310, 345); S4(600). [(7) and (1)].

(11) $\frac{e}{m} = \frac{v}{H\rho}$: Tm3(564).

(12) $\frac{e}{m} = \frac{2xv^2}{F(l^2 - b^2)}$: W5(561, 261); S1(346); S4(603); Tm3(564).

$\frac{e}{m} = \frac{v^2 x}{A}.$

(14) $\frac{e}{m} = \frac{A}{B^2} \cdot \frac{y^2}{x}$: W5(561, 261); Tm3(567). [(7) and (12)].

(21) $\frac{e}{m} = \frac{c^2}{2V\lambda^2_n} (\Delta\lambda_n)^2$: S5(464, 894).

3. CALCULATIONS.

For calculation of the effect of lack of uniformity of the magnetic field upon the deflection see W4(426). For experimental method of integrating non-uniform field see Tm3(565).

VELOCITY OF RAYS, from simultaneous magnetic and electrostatic deflection using formula (13).

Maximum velocity is a function of the cathode fall and varies from 10^7 to 2×10^8 cm. (15,000 v.): W3(449); Ew3(306); W5(561, 263); Tm3(571); cf. Ew2(501); Ew1(186).

Maximum velocity for voltages above 15,000 v. is 2×10^8 cm.; W5(561, 263); Tm3(571); Tm8(668).

Velocity approximately the same for all the rays of one kind, as shown by the shape of the deflection streak: W5(561, 261); W6(588); Tm3(569); W8(664); St1(686). H rays have velocity $\sqrt{2}$ times that of H_2 rays.

VELOCITY OF THE SOURCES OF THE LIGHT SHOWING THE DOPPLER EFFECT.

Maximum velocity varies from 30 per cent to 85 per cent of the velocity of the canal rays computed from the cathode fall and the probable value of e/m: Ps2(257); SHK(464); S13(36, 417); S19(399).

Sources of the H series lines: Ps2(252); S13(36, 417). See Fig. 61. For low voltages the displaced line is composed of two lines whose maximum shifts are to each other as 1 : $\sqrt{2}$

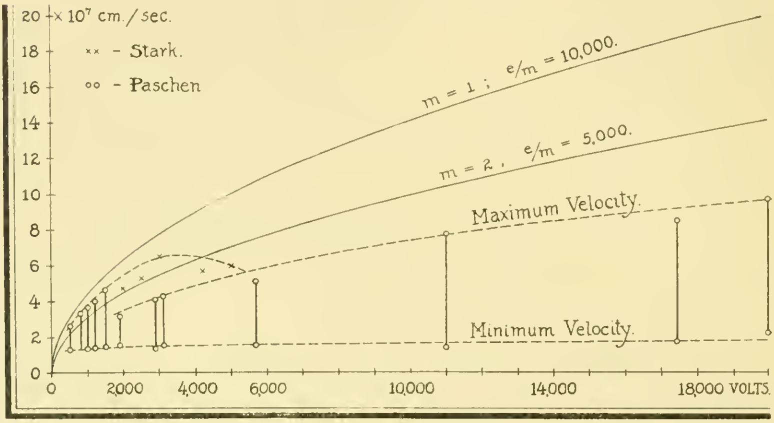

FIG. 61.—Range of velocities of sources of H lines as a function of the cathode fall in volts. Full lined curves are calculated, using formula (1).

Sources of O spark lines: Ps3(263); S23(815). See Fig. 62. Phenomenon seems similar to that with H, data not so complete.

Sources of He lines:

Maximum velocity half that calculated for the canal rays assuming e/m = 2500, m = 4: D1(590).

Sources of C lines:

Maximum velocity 0.9 times that calculated for canal rays assuming e/m = 800, m = 12: Kn3(36).

SPECIFIC CHARGE, e/m.

From magnetic deflection, equations (7) and (10), maximum values are:

In air. e/m = 10^4 (H_2 carefully eliminated): Tm3(569). Other values obtained range from 3×10^2: W2(12); W3(449), and 3.6×10^3: W5(561, 264), to 3.6×10^4: W4(432, 435).

In H_2. e/m = 10^4: W8(660, 662, 663); Tm3(571); Rau1(422).

In O_2. e/m = 10^4 (approximately): W5(562, 265): W8(663); Ew3(306).

In He. e/m = 10^4: Tm3(571); cf. Rau1(522).

In Ar. e/m = 10^4: Tm3(573).

At extremely low pressure, deflection strip divides into two patches, the maximum deflection of second giving for all gases (H, He, Air, Ar, Ne) e/m = 5×10^3: Tm3(571); Tm8(664).

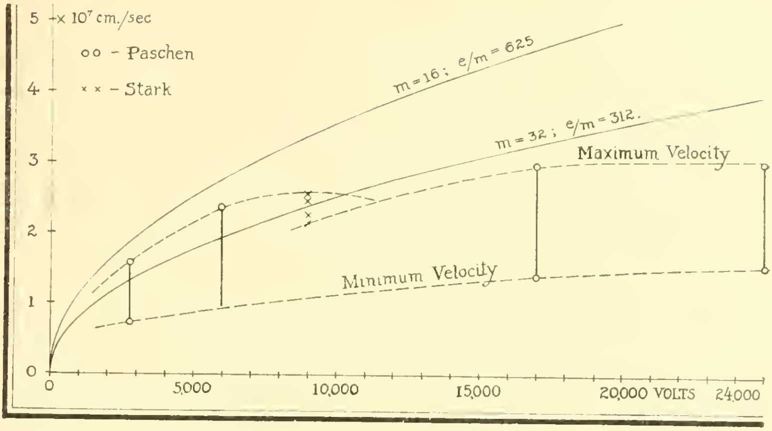

FIG. 62.—Range of velocities of sources of O spark lines as a function of the cathode fall. Full lined curves calculated from formula (1).

With He, a third patch may be divided off for which maximum $e/m = 2.9 \times 10^3$: Tm3(571).

Maximum value of e/m independent of the pressure of gas: Tm3(575).

From Doppler effect, assuming the canal rays are the sources of light:

For H. $e/m = 7{,}500$ for $V < 2{,}000$ v.: S13(35, 416); Ps2(253).
$= 3{,}000$ for $V > 2{,}000$ v.: Ps2(253).

For O. $e/m = 500$ for $V < 3{,}000$ v.: Ps3(264); $e/m = 584$, S23(816).
$= 180$ for $V > 3{,}000$ v.: Ps3(264).

For C. $e/m = 500$ to 670: Kn3(36, 37).

For Al. $e/m = 200$: S23(823).

In general. As judged from the magnetic deflection, results are of same order for O, H, CO_2, He, Ar, and Air: W6(588); Tm3(575); Tm6(295).

Extreme precautions to get rid of H_2 do not affect result: Tm7(361); W8(661). In each gas, however pure, there seem to be besides rays characteristic of the gas (detected by the Doppler effect), also two kinds of rays having a specific charge equal to that of a singly charged hydrogen molecule and atom respectively: cf. W10(213).

V. THEORETICAL DISCUSSION AND EXPLANATION.

1. CONSTITUTION OF THE RAYS.

WHAT ARE THE CANAL RAYS?

Not Roentgen rays, do not affect photographic plate: Ar(327); GR(726).

Not cathode rays, much greater mass: Bo1(717).

Identical with first cathode layer particles: G1(692, 699); Wh2(423); Sm4(109). Prolongation of cathode afflux: V1; Wh2(422); Bg1(692).

Consist mostly of positively charged gas atoms, together with some metal atoms from electrodes, according to Doppler effect: Gr; W4(421); Ew3(316); W5(561, 263).

Always contain some rays with same mass as hydrogen atom, as shown by magnetic deflection: Tm3(575). Hydrogen seems to play a unique role in discharge tube phenomena: V2; V4. These singly charged H atoms and molecules may form the greater part of the rays even at high pressures: Hl3(235).

At extremely low pressures, consist mostly of two kinds of particles, singly charged hydrogen atoms and molecules, irrespective of the gas filling the tube: Tm3(575); Tm6(295).

Professor J. J. Thomson's results seem to prove that *various gases under the action of strong electric fields in extreme vacuum, give off identical carriers of positive electricity:* Tm3(575); Tm6(295).

Similar to α-rays: Ew3(310).

PLACE OF ORIGIN.

In gas beyond cathode dark space: W3(451); W4(422); G3(207); S1(133, 507); S4(602); Ew3(301).

Theory: Gas molecules ionized by cathode rays or positive rays from anode, start to move along a line of force, acquire considerable velocity, forming the cathode afflux, and shoot through the canals, forming the canal rays: S4(602). See diagram of lines of force in canals: S1(134, 508).

Not on cathode front surface or in canals because of shadows cast: Wh2; cf. G1(699); Gr; Ew3(299).

Not in dark space, since there is no ionization there and they could not acquire sufficient velocity: S2(583); Ps2(257); Ew3(307).

Not an anode: Ew1(193); Ew3(300); cf. Bg(696); Bo1(717).

EXPLANATION OF NON-HOMOGENEITY (shown by non-uniform magnetic deflection).

Not due to variations of velocity, slower rays would be more deflected, not less: S2(583); Ps3(257); Ew3(307).

Must be due to continuous variation of e/m since deflection streak is not fluted at ordinary pressures: Tm3(569, 572).

Assumption that e or m or both may be integral multiples of unit charge and unit mass (the H atom) respectively, is not sufficient: S2(583); Ps2(255); cf. W9(669, 675); Gr.

Complex nature of the rays, perhaps containing H, N, Al, Hg. atoms, not a sufficient explanation, since carefully purified gases have been tried, and no fluting effect obtained: Tm3; cf. Ew3(316).

Probable explanation. The mean value of e/m for each ray during its passage through the magnetic or electric field, is evidently the quantity which determines the deflection. By collision with stray corpuscles or negative electrons, any canal ray may become discharged and charged again so that its average charge may have any value between +e and —e. This also explains the negative deflection observed: S2(585); W5(561, 263); Tm3(570). See also W4(433, 435); W9(669, 670, 675, 677); Sm4(111); S4(604, 605); Tm1(520); SH(95); Ew3(307).

Other effects mentioned above, as the variation of e and m by steps, complexity of the rays, probably do enter, but are insufficient in themselves to explain the phenomena reported.

Mass may also change en route, molecules being formed of atoms and vice versa: Ew2(501).

Non-homogeneity disappears at very low pressures as then collisions are much less frequent: Tm3(575); Tm6; Tm7.

CHARGE.

While for the most part the rays are positively charged, by collision with negative electrons some of them at various stages of their career become neutralized and later perhaps negatively charged, as evidenced by magnetic deflection experiments: Tm8(670).

2. LIGHT FROM CANAL RAY REGION.

CENTERS OF EMISSION. The negative electrons, from the Zeeman effect: S13(23, 401).

SOURCES OR CARRIERS OF SERIES LINE SPECTRA.

All lines of one series have same carrier: S5(464, 894); S9(113, 250); S13(33, 414).

Sources are positively charged. For confirming experiments see S13(24, 403).

First hypothesis: Sources are the canal rays themselves, positive atoms, singly, doubly, or trebly charged: S5(464, 894); SH(95); S9(113, 250); Rau1(423); S13(34, 39, 415, 419); S23(830).

Main and first and second series of doublets (H, Ca, Hg, C, K, Na) have singly charged atom as carrier: S9(112, 249); S13(36–38, 416–419); SS(461); Kn3(36). Doubtful: S23(830).

Series of triplets of Hg have doubly charged atom as carrier: S9(112, 250); S13(38, 419); SHK(465). Doubtful: S23(830).

Some Hg lines, λλ 4078, 4347, appear to have trebly charged atom as carrier: S13(38, 419); SHK(468).

Note.—This hypothesis seems to be rendered doubtful by the discrepancy between the maximum velocity of the rays and that of the sources of the light showing the Doppler effect. If true, since the canal rays must probably be rendered luminous by the collision which ionized them, and emit most light while speeding up, no intensity minimum would be expected.

Second hypothesis: Sources are gas molecules hit and ionized by the rays. To see how this explains the curve of maximum velocities Fig. 61, consider the case of H rays and H_2 rays, having velocities u and 0.71 u respectively. Assuming perfectly elastic collision, maximum possible velocity is, for the collision of

(1) H ray with H atom, 1.00 u; (4) H ray with H molecule, 0.71 u;
(2) H_2 " " H " 0.94 u; (5) H_2 " " H " 0.67 u;
(3) H " " H_2 ray, 0.90 u; (6) H " forming " 0.71 u;

Assuming collision is not perfectly elastic, energy being lost in radiation and ionization, and that collisions of types (1), (2), (3), are less important with the higher cathode falls, the curve is accounted for.

Now to see whether this hypothesis explains the intensity minimum. Assuming; that gas molecules hit squarely enough to be ionized, alone emit light, the canal rays being mostly neutralized by the collisions; that ionization occurs only when the energy imparted exceeds a certain minimum; and that the intensity of the light emitted is proportional to the momentum given to the molecule as a result of the collision; the author has calculated by a laborious statistical method (starting with 10,000 canal rays and computing the directions and magnitudes of the velocities of the gas atoms hit in five generations of collisions) the probable distribution of intensity in the resulting Doppler effect. One set of curves is shown in Fig. 63.

The intensity minimum is seen to be distinct and of fairly constant width, in spite of the fact that the number of sources with small velocities is much greater than the number of the swifter sources. The importance of more data regarding the deflection streak and the Doppler effect so as to decide between these two theories is obvious.

Carriers of Band Spectrum. (Stark's hypothesis.)

Not the positive atoms while in motion since light shows no Doppler effect: S5(464, 894); SH(95).

Probably neutralized atoms formed by the collision of charged rays with gas atoms, the former being stopped by the collision: S4(605); S5(461, 893); S12(355); S13(43, 425); S19(399); Ew3(314).

Why canal rays neutralized by electrons and retaining their velocity do not emit the band spectrum is not explained.

Doppler Effect, Intensity Minimum.

Explanation. Either

(1) Rays of slow velocity are relatively few: W5(561, 263); W6(588); W8(663); S2(583); S13(31, 412); St1(686); Tm3(569). This assumption fails to explain the constancy of width of the intensity minimum; or

(2) Intensity of radiation is a function of the velocity: S10(253); S13(31, 177, 180, 412, 435, 439); Kn3(36); Ps2(259).

Velocity must exceed a certain minimum or no displaced line is obtained: S13(180, 439).

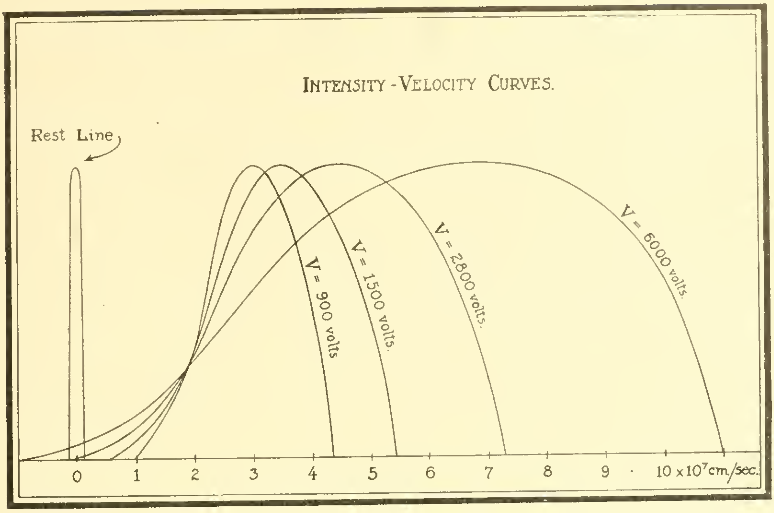

FIG. 63.—Doppler effect to be expected if sources of light are H gas atoms hit by H canal rays of fairly uniform velocity.

DOPPLER EFFECT, STATIONARY INTENSITY.

Explained as due to emission of light either

(1) By a positive atom on collision with a neutral atom which stops it, the intensity being proportional to the gas density: S13(172, 430). This hypothesis is not reconcilable with the existence of the intensity minimum; or

(2) By neutral atoms ionized by secondary negative rays created by the canal rays: S19(398); S22(917).

SHIFT TOWARDS THE RED.

Theoretical importance in deciding between the various electromagnetic theories of the emission of light by electrons in motion, those of Bucherer, Einstein, and Lorentz: St1(293).

EMISSION OF LIGHT BY AN ATOM.

The Doppler effect shown by light assumed to come from canal rays, since it may give a means of distinguishing the light emitted by singly charged atoms from that emitted by those which are neutral or doubly charged, promises valuable data as to the circumstances, even the mechanism concerned in this radiation of light. However, no theories advanced so far explain satisfactorily the phenomena observed, hence deductions from them seem premature. The theories are as numerous as the writers and at the present stage, it seems unnecessary to attempt the difficult task of abstracting them, but a partial list of articles on the emission of light by an atom based on the results of investigations with canal rays is subjoined: S8(104, 109); S10(251, 253); S12(360); S13(40, 174, 422, 432); Hl2(17–20); W11(428, 437); S16(80); SW; Ps2(259); St1; St2(683); S22. Also—

P. Lenard	Ann. Phys. 17, 187.
C. Fredenhagen	Verh. Deutsch. Phys. Ges. 9, 393-401.
C. Fredenhagen	Phys. Zeitschr. 8, 729–737, 927–9.
G. Schott	Phys. Zeitschr. 9, 214–216.
G. Schott	Phil. Mag. 15, 172–198.
G. Schott	Ann. Phys. 25, 63–91.
J. Stark	Phys. Zeitschr. 9, 85–94.

3. CHEMICAL EFFECTS.

No Direct Chemical Action of the rays other than that of splitting up the gas molecules, releasing their latent chemical activity.

Hence in O_2 oxidation takes place, in H_2 reduction: Sm2(708–710); Sm3(622); Sm4(113); S4(654); Ew3(304).

Disintegration. Double dependence on metal and gas indicates chemical process, perhaps indirect. Not sensitive to traces of impurity: Kl1(872).

Fluorescence.

(1) Explained as due to pressure of impact of rays: Tf1(616); Tf2; Ew3(304).

(2) Explained as accompanying chemical reaction indirectly produced by the rays, varying with the gas: Sm2(710).

Na light not the result of heating or oxidizing process: Rau1(421).

Solid solutions. Fluorescence explained

(1) as accompanying reduction of higher oxides: W7.

(2) as accompanying reduction of active compounds: Sm3(622).

4. SECONDARY EMISSION OF CATHODE RAYS.

Uniform Maximum Velocity explained by assuming electrons are merely released by canal rays, being shot out by the atom with a definite velocity. Distance penetrated by the rays determines how thick a layer the cathode rays must pass through before emerging, hence determines the distribution of cathode rays of less velocity: F2(750); F3(302).

Increase of Intensity with Angle of Incidence is explained by assuming canal rays do not penetrate so far, hence negative rays are not so much absorbed in emerging. Effect is more marked with Al than Cu since rays penetrate farther in the former: F3(306, 307).

Negative rays may be created by ultra-violet light or Roentgen rays, but probably not: F2(750); F3(301).

Amherst College, Amherst, Mass.,
November 1, 1908.