

# Fadenstrahlrohr

Ein **Fadenstrahlrohr** ist ein physikalischer Versuchsaufbau, bei dem sich beschleunigte Elektronen in einer Kugel aufgrund der Lorentzkraft, die ins Kugellinnere gerichtet ist, auf einer Kreisbahn bewegen. Beim Zusammenstoßen mit Gasmolekülen entsteht Licht, welches die Kreisbahn der Elektronen sichtbar macht.

## Versuchsaufbau

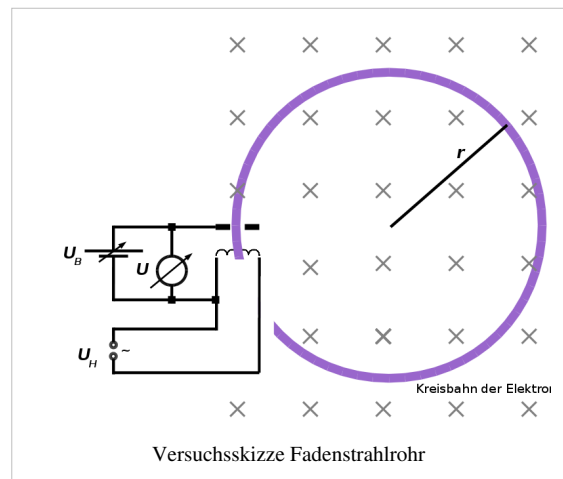
In einen evakuierten Glaskolben wird etwas Wasserstoffgas ( $H_2$ ) gefüllt, so dass im Kolben eine Wasserstoffatmosphäre bei niedrigem Druck (ca. 1 Pa) entsteht. Der Druck ist so bemessen, dass die Elektronen durch Zusammenstöße möglichst wenig abgebremst werden (Änderung der kinetischen Energie), die Zahl der Zusammenstöße aber zu einem sichtbaren Leuchten ausreicht. Im Kolben befindet sich eine Elektronenkanone. Diese besteht aus einer Heizspirale, einer Kathode und einer Lochanode. Aus der Kathode treten Elektronen aus, die zur positiv geladenen Anode hin beschleunigt werden. Durch ein Loch in der Anode verlassen die Elektronen das Strahlerzeugungssystem und werden im Wehneltzylinder gebündelt.

## Ergebnis

Beim Einschalten der Heizspannung erhitzt sich die Heizspirale und Elektronen treten aus ihr heraus. In dem elektrischen Feld zwischen Anode und Kathode wirkt das elektrische Feld auf die Elektronen, das diese auf eine hohe Geschwindigkeit beschleunigt, sodass die Elektronen durch eine kleine Öffnung in der Anode diese als Elektronenstrahl verlassen. Da der Spulenstrom nicht eingeschaltet ist, wirkt keine Kraft auf den Strahl und er behält seine Richtung bei. Wird nun aber der Spulenstrom zusätzlich eingeschaltet, lenkt die Lorentzkraft die Elektronen auf eine Kreisbahn.



Fadenstrahlrohr mit Helmholtzspulenpaar

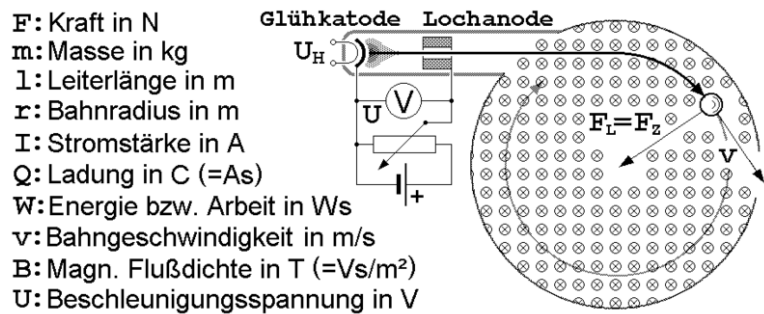


Versuchsskizze Fadenstrahlrohr

## Bestimmung der spezifischen Ladung des Elektrons

Je höher der Spulenstrom ist, desto kleiner wird der Radius der Kreisbahn, da das Magnetfeld stärker wird. Die Stärke des Magnetfeldes und die Lorentzkraft sind zueinander proportional, so dass auch die Lorentzkraft zunimmt. Eine größere Lorentzkraft lenkt die Elektronen stärker ab, weshalb die Kreisbahn kleiner wird.

Die Lorentzkraft  $F_L$  steht immer zur augenblicklichen Bewegungsrichtung senkrecht und ermöglicht als Zentripetalkraft  $F_Z$  die Kreisbewegung. Den Betrag der Geschwindigkeit und folglich die Bewegungsenergie kann sie nicht ändern:



$F$ : Kraft in N  
 $m$ : Masse in kg  
 $l$ : Leiterlänge in m  
 $r$ : Bahnradius in m  
 $I$ : Stromstärke in A  
 $Q$ : Ladung in C (=As)  
 $W$ : Energie bzw. Arbeit in Js  
 $v$ : Bahngeschwindigkeit in m/s  
 $B$ : Magn. Flußdichte in T (=Vs/m<sup>2</sup>)  
 $U$ : Beschleunigungsspannung in V

### Herleitung der Formel für die spezifische Ladung $Q/m = f(U, B, r)$

$$F_{\text{Lorentz}} = F_{\text{Zentripetal}} \quad W_{\text{Beschleunigung}} = W_{\text{kin}}$$

$$B \cdot I \cdot l = \frac{m}{r} \cdot v^2 \quad Q \cdot U = \frac{m}{2} \cdot v^2$$

$$B \cdot Q \cdot v = \dots \quad \frac{Q}{m} \cdot 2U = v^2$$

$$\dots = \frac{m}{r} \cdot \frac{Q}{m} \cdot 2U \quad \frac{Q}{m} = \frac{v^2}{2U}$$

$$v = \frac{2U}{B \cdot r} \quad \frac{Q}{m} = \frac{2U}{B^2 \cdot r^2}$$

$$v^2 = \frac{(2U)^2}{B^2 \cdot r^2}$$

Stellung der beteiligten Vektoren

Herleitung der Formel zur Bestimmung der spezifischen Ladung des Elektrons mit Hilfe des Fadenstrahlrohr-Versuchs

$$F_L = F_Z$$

$$e \cdot v \cdot B = m \cdot \frac{v^2}{r}$$

Daraus erhält man für den Betrag der spezifischen Elektronenladung

$$\frac{e}{m} = \frac{v}{B \cdot r}$$

Die Bestimmung der Geschwindigkeit erfolgt mit Hilfe des Energieerhaltungssatzes

$$e \cdot U = \frac{1}{2} \cdot m \cdot v^2$$

Damit folgt schließlich

$$\frac{e}{m} = \frac{2U}{r^2 \cdot B^2}$$

Die spezifische Elektronenladung hat den Wert

$$\frac{-e}{m} \approx -1,7588202 \cdot 10^{11} \frac{\text{C}}{\text{kg}}$$

Da die Ladung eines Elektrons aus dem Millikan-Versuch zugänglich ist, dient das Studium der Elektronen im Magnetfeld der Bestimmung ihrer Masse gemäß:

$$m = \frac{e \cdot r^2 \cdot B^2}{2U} \approx 9,1094 \cdot 10^{-31} \text{ kg}$$

Ähnliche Konzepte für die Wägung von geladenen Teilchen findet man beim Massenspektrometer.

## Weblinks

- Das Fadenstrahlrohr <sup>[1]</sup>.

## Referenzen

[1] [http://leifi.physik.uni-muenchen.de/web\\_ph10/versuche/10\\_fadenstrahl/versuch/fadenstrahl.htm](http://leifi.physik.uni-muenchen.de/web_ph10/versuche/10_fadenstrahl/versuch/fadenstrahl.htm)

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