Coils and Electromagnetic Field Strength

Introduction

Research Question

Does the amount of coils involved in creating an electromagnetic field affect the strength of that same electromagnetic field?

Experimental Variables

Independent variable - amount of coils used in creating an electromagnet
Dependent variable - the strength of the electromagnetic field
Control variable 1 - voltage
Control variable 2 - resistance
Control variable 3 - diameter of coils
Control variable 4 - diameter of wire

Background

I have an interest in space travel and I would like to see humans travel the stars. I think that the future of setting up facilities in outer space and launching items into space from our planet will be done by electromagnetic induction from a rail gun like launcher.
I think having a large slope like platform and then launching a small pod filled with machinery, robotics, and materials would be an excellent way to send up basic items needed by any humans in space. This would have the result of lowering the total weight of the rocket ship (if any is needed at all) and making the utilization of a rocket ship use less materials and resources to get into the atmosphere, meaning it can go even faster once it's out of our atmosphere.
I want to learn about methods to boost the total strength of an electromagnetic field firsthand so that one day I can say I aided in creating and designing the next era of space travel. I want to have laid my hands on the foundation supporting our future.

Scientific Understanding

Amount of coils used in creating an electromagnet

As a current travels through a copper wire it creates a magnetic field around itself that takes the shape of a circle around said wire [citation 1]. This is what is called an electromagnet. Each electromagnet has a basic strength associated with it, according to various factors such as voltage, resistance, and the wire thickness. If the wiring were to become curved and looped into a circle, then the field would become focused in an area flowing through the hole and around the edges of the wiring and then back through the hole [citation 1]. The query of the experimentation that is to be conducted is to determine if the magnetic field strength of one loop of wire increases in any way with the inclusion of additional coils of wire.

The strength of the electromagnetic field

An electromagnetic field is a phenomenon that can exert force on another object that is receptive to the magnetic field. A field can be found in nature alongside specific elements and compounds, and can also be created by running a current through a copper wire. The strength of a magnetic field created using wiring can be manipulated utilizing various factors such as voltage, resistance, and wire thickness.

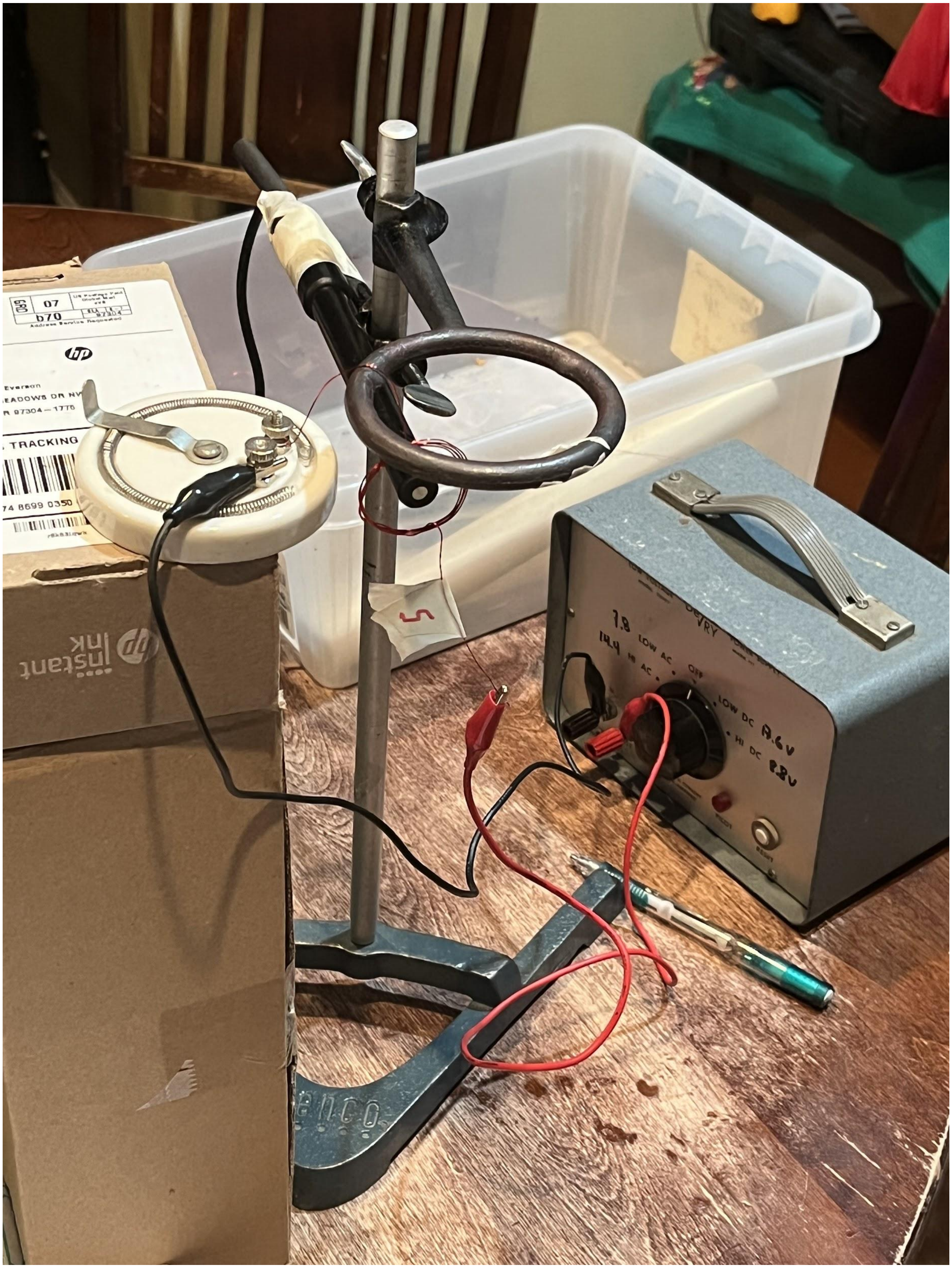
Voltage

Voltage is the difference in electrical potential between two points [citation 1]. When electrons carrying electrical potential (Voltage) travel through a wire, an electromagnetic field is produced [citation 4]. Modulations in voltage can change the strength of a magnetic field when applied to a wire [citation 3].

Resistance/Diameter of wire

The wire width used has an effect on the strength of the magnetic field due to resistance being inversely proportional to the cross-sectional area of wiring. If a wire width is increased then the current will increase due to a lower resistance, which would in turn allow the magnetic field to grow stronger assuming the same voltage used in both trials. [citation 3] If a resistor is added to a copper wire coil so as to allow for a longer amount of time for the circuit to be live, then the measured electromagnetic field as resulted from the added resistance would be lower. This was something that was taken into consideration while reviewing the created experiment procedure, and I made the decision that have values that did not reflect the magnetic field of the coils themselves with their infinitely small resistance was acceptable because the goal of this exploration is to discern if an increase in the number of coils affects the magnetic field strength.

Lab Setup



Procedure

Phase 1: Preparation of Materials

1) To start off, I measured the diameter of the wire to measure one of my control variables. I then took the uncertainty value of my measuring tool that was written on its container and made note of both the uncertainty and the actual measurement.
2) I then wrapped the wire around a pvc pipe to create coils of copper. I created 7 clusters of coils, with the number of coils per cluster initially starting at five and increasing by 5 until I created a cluster of 35 coils.
3) Then, to measure the second control variable of the four that I am accounting for, I measured the diameter of each coil cluster and found the average diameter and corresponding uncertainty, and then made note of them both.
4) One important decision I made was related to the amount of time I was measuring for. Because copper has an infinitely low resistance and because I wanted to get a decently lengthy measurement time to account for potential fluctuations, I decided to add an additional resistance. This would not interfere with the determination of whether an increase of coils would affect the strength of the magnetic field because I would be using the same resistance setting on the round resistor for all trials, so any change that occurred would not be the fault of the resistance.
5) To make note of the third control variable of the experiment, I measured the resistance of the resistor and also gleaned the uncertainty from the ohmmeter.
6) I then acquired a battery for running current through a wire. I made note of the fourth control variable of the experiment by discerning the voltage value that I would be using in my experiment and also the corresponding uncertainty from the written information on the battery.

Phase 2: Set Up

I now needed to set up my experiment, account for all safety concerns with adequate preventative measures, and prepare for data collection.

1) To start off, I used a large stand from my physics teacher’s classroom that would act as the base of the experiment.
2) I then taped a vernier magnetic field measuring device to the stand to the point where it was horizontal with the surface the stand was resting on so as to have the data collection ignore the earth’s gravity.
3) I then took the battery and connected wiring to it.
4) I assembled some boxes that I found lying around and then stacked them up so that I could place the resistor on top of them. I did this in order to get the resistor close to the experiment so that I could angle the wire over the large ring found on the stand and get the wire to hang straight down so that it’s circle center could fall right in the center of the vernier measuring device.
5) I then connected the black wire to the resistor.
6) I then connected the vernier magic wand to a measuring device that was able to interpret and graph the data collected from the vernier magnetic field measuring wand.

7) For my first step to ensure my safety during this experiment, I believed that both the wire and the resistor would get quite hot so I grabbed myself some gloves to protect myself from being burned by maneuvering the coil cluster around and connecting new coil clusters to the resistor.
8) For my second step to ensure my safety during this experiment I made sure to have an adult on hand. I worked on this both in my physics classroom and at home, therefore I could not rely solely on my teacher. Because I was working with electricity, there was the possibility of something going wrong and sparks flying. If something were to happen that would threaten my safety, I wanted to ensure that an adult was present to assist me. This was also the reason for my third step to ensure my safety during this experiment, which was me wearing safety glasses, so as to avoid any potential sparks flying into my eyes.
9) For the fourth step meant to ensure my safety, because of the potential of sparks flying, I hid behind the pillar I had created for the resistor in order to protect my head and upper torso. I also wore a long sleeve jacket so that my arm that was on standby to turn off the battery at a moment's notice was also protected.

Phase 3: Data Collection

1) The first step I took in terms of data collection was equipping my thick jacket, gloves, and safety glasses. I also ensured that an adult was aware that I was experimenting and was watching over me.
2) The next thing I did was hooking up the first coil cluster, which was the five coil cluster. I connected one strand on the end of the coil to the resistor, and then I connected the other strand on the other end of the coil to the red wiring that was hooked up to the battery.
3) After the circuit was closed, I angled the coil cluster so that the circle center was aligned with the vernier magnetic field measuring wand. On the vernier measuring wand, there was about an inch between the tip and a white line communicating where it could turn and angle itself in a different direction so as to be perpendicular to the direction of the wand. For the five coil cluster, and for every trial for every coil cluster afterward, I positioned the cluster to be halfway between the tip and the white line.
4) Now that everything was set up, I ducked behind the pillar I made for the resistor and turned the battery on to the 17.6 Voltage option. I then let it run for 15 seconds and then turned the battery off.
5) I observed the data graphed on the measurement equipment. I initially wanted to take note of the median of the graph found because I thought that if the graph was skewed or lopsided either towards the maximum or minimum that would be better, but then I found that each data collection done for each coil cluster was sinusoidal. This made me think that a better approach would be to simply find the average. Thus I made the decision to observe the average of the graph. After observing the data found for trial one of the five coil cluster, I found the average of the data gathered and also the maximum and minimum data points gathered.
6) After the observation of trail one, I then repeated steps 3-5 twice more.
7) Once I had gathered data three times for the five coil cluster, I unhooked the cluster and repeated step 2 with the 10 coil cluster instead of the five coil cluster.

8) I proceeded to repeat steps 3-5 three times for the 10 coil cluster.
9) I repeated steps 2-5 five more times, swapping out the coil clusters for the next coil cluster in line to be tested, so that all seven coil clusters, from 5 coils-35 coils, were tested, with 21 total trials having been completed.

Phase 3) Wind down

1) To ensure my safety even after the experiment had concluded, I let all of the materials simply sit out for an hour before attempting to move them in an attempt to let them cool down. I then placed all of the materials involved in the preparations of materials phase and in the set up phase into a plastic box to keep them all in one location.

Data Analysis

Raw Data Table

The effect of the amount of coils used in an electromagnetic field on strength of the same electromagnetic field			
Amount of Coils	**Strength of the electromagnetic field (+/-0.004) mT**		
	Trial 1	**Trial 2**	**Trial 3**
5	**0.424**	**0.423**	**0.417**
10	**0.717**	**0.740**	**0.770**
15	**1.141**	**0.857**	**0.987**
20	**1.372**	**1.372**	**1.429**
25	**1.562**	**1.625**	**1.694**
30	**1.942**	**1.959**	**2.087**
35	**2.185**	**2.178**	**2.128**

Control Variables Involved in the raw data collection	
Voltage (+/- 0.1 volts)	**17.6**
Resistance (+/- 0.1 ohms)	**3.8**
Diameter of Coils (+/- 1.50 millimeters)	**36.16**
Wire Diameter (+/- 0.02 millimeters)	**0.44**

Uncertainty related to the amount of coils

There is no uncertainty associated with the measurement and understanding of the quantity of coils. It is an increase by integer numbers with no room for uncertainty through observation. It is infinitely sure of how many coils there are.

Uncertainty related to strength of the electromagnetic field

The uncertainty for the strength of the electromagnetic field was found by looking up the specifications of the vernier magnetic field measurement wand on the vernier website. [Citation 2]

Uncertainty related to voltage

The uncertainty for the strength of the electromagnetic field was based on what was stated on the battery utilized to run the current through the electromagnetic field.

Uncertainty related to resistance

The uncertainty of the resistance measured was determined based on what was stated on the ohmmeter utilized.

Uncertainty related diameter of coils

The uncertainty of the diameter of the coils was determined by subtracting the minimum diameter measured from the maximum diameter measured and then dividing this range by two.

Uncertainty related to the thickness of the copper wire

The Uncertainty related to the thickness of the wiring used for the electromagnetic field was found by utilizing an electronic device and the written uncertainty found on the machine.

Processed Data Table

The effect of the number of coils in an electromagnetic field on strength of the same electromagnetic field		
Number of Coils	**Average Strength of the electromagnetic field (mT)**	**Uncertainty of Measured Value**
5	**0.421**	**0.031**
10	**0.742**	**0.053**
15	**0.995**	**0.036**
20	**1.391**	**0.072**
25	**1.627**	**0.091**
30	**1.996**	**0.175**
35	**2.164**	**0.184**

Average strength of electromagnetic field calculation

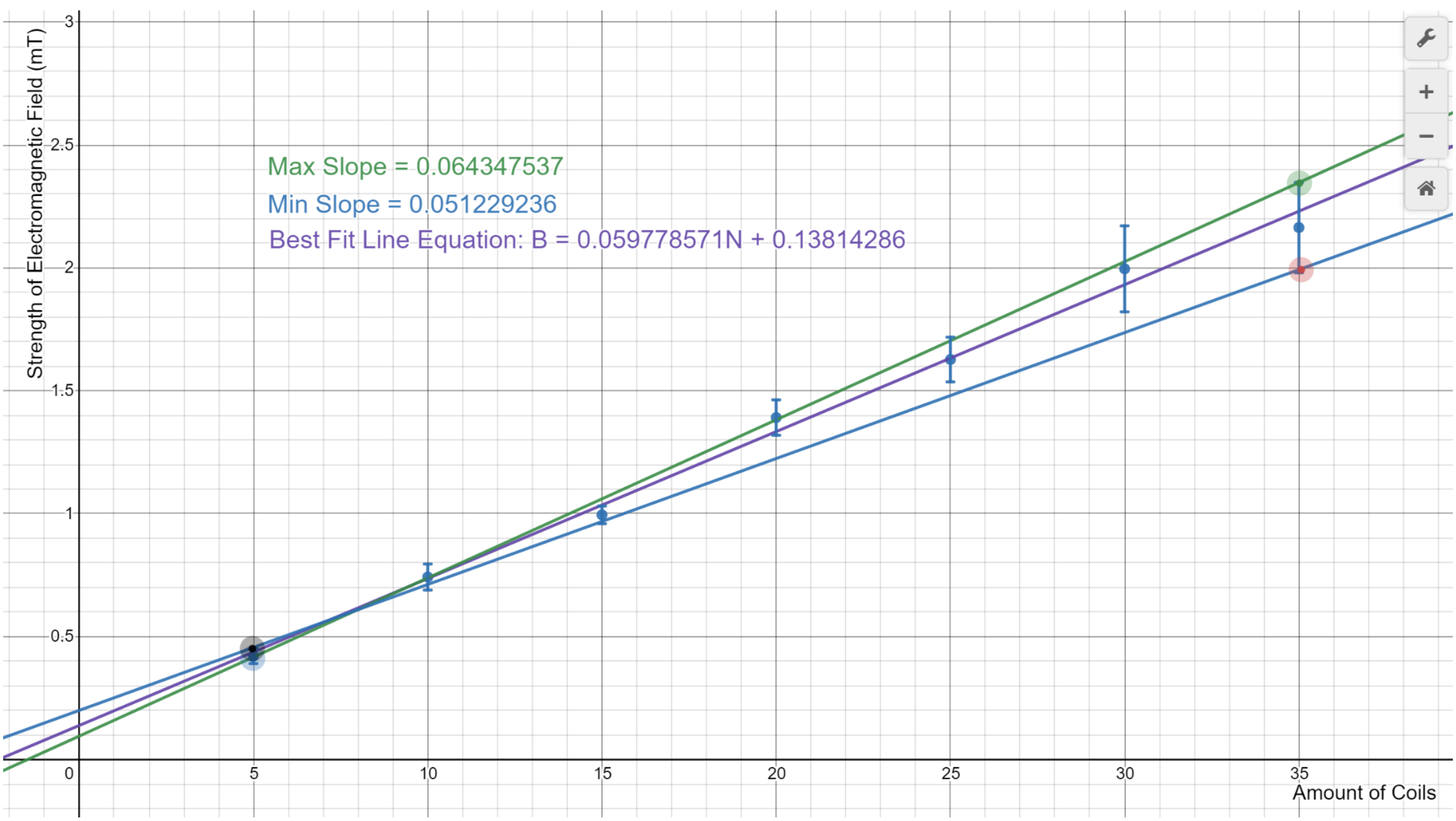
$$A = (T1 + T2 + T3)/3$$

Where A is the average strength of the electromagnetic field, and where T1, T2, and T3 are each equal to Trial 1 data, Trial 2 data, and Trial 3 data respectively. A division of 3 is also necessary due to there being three trials conducted per amount of coils.

Uncertainty related to the average strength of the electromagnetic field

The uncertainty of the processed data was found by finding the range of each measurement and dividing that range by two to get the uncertainty related to each data point. This was possible because of the fact that I consistently measured for 15 seconds and the fact that the measurements were often sinusoidal. After I found the uncertainties I then added the three uncertainties relating to the three data points per amount of coils, and then divided that sum of the uncertainties by the constant 3. I then compared the calculated uncertainty to the uncertainty given with the tool of the battery and utilized the larger of the two numbers which in every case was the calculated uncertainty. This gave the uncertainty of measured value found in the processed data table.

Processed data graph



Conclusion

Discussion of Results

The data collected seemed to be best described as a linear function. The equation of my best fit line was $B=0.060N+0.138$, where B represents the strength of the magnetic field and N represents the amount of coils utilized in inducing an electromagnetic field. There are two constants in this equation (0.060 and 0.138). 0.060 represents the gradient of the linear relationship, meaning it relates to the increase in strength of magnetism as the number of coils utilized in an electromagnet increases, given voltage, resistance, diameter of the coil, and diameter of the wire are all the same as utilized in the lab. If any of these variables are changed, I would expect a change to the gradient constant. 0.138 represents the y-intercept of the equation of the best fit line, meaning it relates to the baseline level of strength that would come from an electromagnet with no coils, which would be a straight wire with a current flowing through it, assuming the same voltage, current, and wire diameter as were utilized in the lab. If any of these variables are changed, I would expect a change to the y-intercept constant.

I feel like the best fit line describes the overall behavior of the lab since 6 of the 7 data points fall on the line within the error bars. However, I am skeptical that this line is a perfect fit because the third data point and the corresponding error does not fall on the best fit line and is in fact below it.

Improvements and Extensions

The first improvement I would make would be to increase the time spent recording data. 6 out of the 7 data points were on the line of best fit, but the one that wasn’t had an uncertainty that was slightly below the best fit line. This was likely the result of the data not picking up the entire sinusoidal wave, and instead picking up only a portion that does not include the maximum and/or minimum.

The second improvement I would make to the experiment is to acquire and utilize a voltmeter in my experiment to measure the voltage. It is moderately likely that the sinusoidal pattern of the waves was a result of the battery utilized in the experiment modulating around the voltage output from said battery.

The final way that I’ve found that could improve the experiment is to acquire one spare of each component of the experiment (battery, wiring, resistor, etc.), and swap out a single element of the experiment to determine if that element is potentially faulty. If I were to swap out the battery and it would give a different reading on my measurement device, then it can be inferred, assuming all else equal, that the battery was manipulating the results. This would require an increase in the quantity of trials conducted and time spent measuring.

Footnote References

[1]
Scientific Background

[2]
https://www.vernier.com/product/magnetic-field-sensor/

[3]
https://easierwithpractice.com/does-the-thickness-of-the-wire-affect-the-magnetic-field/

[4]
https://www2.lbl.gov/MicroWorlds/teachers/movingelectrons.pdf