Contact Forces, Friction and Problem Solving Strategies

And a guide to this week's homework

New and experimental type of homework

- Calibrated peer review.
- Aim - to show you how different people go about solving problems.
- To give you experience of how your exam questions will be marked.

Problem Solving Strategies

Some hints for how to solve Physics problems better

Based on research

- These are the methods that effective physicists and students use.
- They may seem cumbersome but they pay off long term.
- To encourage you to practice using them, marks will be given for using these methods in all human-marked work (including the exam)
- You've seen them in action in the webcasts

Hint 1: Make sure you understand the question

- VERY common error - students read a question cursorily, jump to conclusion that it's like one they've done before, solve wrong problem.
- Draw a diagram. Make sure you know what is where, which forces are acting on what etc.
- Make sure you understand what the question is asking: paraphrase it in your own words.
- Questions that sound similar can be quite different.

Hint 2: Think about principles and approximations **first**

- Think about the physical principles that might apply. e.g. use torques, energies...
- Use your common sense to guess what might happen.
- Write down what principles you will try. NOT JUST WHAT EQUATIONS.
- Write down what assumptions you are planning to make. e.g. neglect friction

Hint 3: Use symbols, not numbers

- This allows you to check dimensions/units and the functional form.
- If you need to re-do a calculation with different numbers, it saves you LOTS of time.
- Do your calculation using symbols, not numbers. e.g. g, not 9.8.
- If you are given a number, choose a symbol for it and use the symbol.
- Only put numbers in for the symbols right at the end.

For example

- A ball is thrown upwards at a speed of 20 m/s. How high will it get?

Bad solution

- A ball of mass 2kg is thrown upwards at a speed of 20 m/s. How high will it get?

$$2 \times 9.8h = \frac{1}{2} 2 \times 20^2 = 400$$

$$h = \frac{20^2}{2 \times 9.8} = 20.4\ m$$

Good solution

- A ball of mass 2kg is thrown upwards at a speed of 20 m/s. How high will it get?

Let m be the mass, v the starting velocity and h the height reached. Use energy conservation - initial kinetic energy becomes final potential energy

$$mgh = \frac{1}{2} mv^2$$

$$h = \frac{v^2}{2g} = \frac{20^2}{2 \times 9.8} = 20.4m$$

Hint 4: Check your working and Answers

- Using the three methods we've already talked about - plausibility, behaviour and units/ dimensions.

Contact Forces and Friction

Continued...

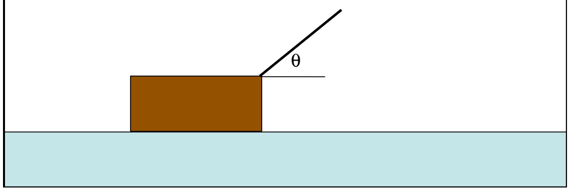
Reminder - normal force

- When one object touches another, it causes it to compress a bit.
- It acts as a spring and pushes back.
- You work out how strong this push is by figuring out what force is needed to stop the objects sinking into each other or bouncing apart.

For example

You are dragging a box of mass M along the floor at a constant speed. You do it by pulling on a rope with force T.

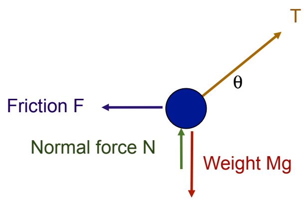
What is the normal force?



Draw a free-body diagram

- Show the box as a dot
- Show only the forces that act ON THE BOX

Free-body diagram…

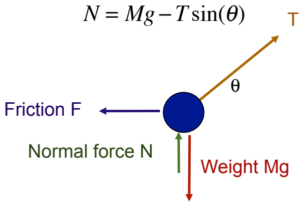


Now what's the equation for the normal force?

Free-body diagram…

Forces perpendicular to the surface (vertical in this case) must balance. So -

$$T\sin(\theta)+N=Mg$$
$$N=Mg-T\sin(\theta)$$



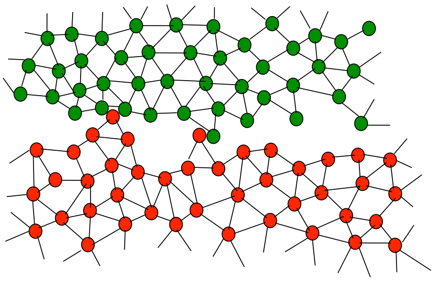
(as it's not accelerating, horizontal forces must balance too - so

$$F=T\cos(\theta)$$

But that's not the only force when things contact

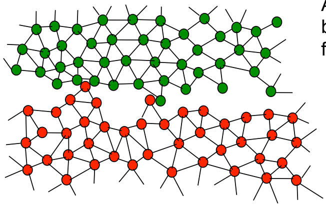
- There is also a friction force.
- It opposes the "relative" motion.
- Where does it come from?

At a microscopic level, surfaces are not flat.



Microscopic bumps collide

- Opposite surfaces can form transient chemical bonds.



As bumps get caught, bonds are torn and re-form.

Rubbing sets up vibrations in both surfaces, heating them up.

It's very complicated…

- **Tribology** is the science and engineering of interacting surfaces in relative motion. It includes the study and application of the principles of friction, lubrication and wear. The word 'tribology' derives from the Greek root *τριβ-* of the verb *τρίβω* - *tribo* "I rub", and the suffix -logy.

Exactly what happens depends on…

- The chemistry of both surfaces
- The exact smoothness of both surfaces
- Any oxidation of the surfaces
- Microscopic layers of moisture or grease
- Lubrication
- and much more…

So what can we do?

- On the face of it - give up.
- This is so complicated that we could never come up with an accurate theory.
- But - we could maybe do some experiments and see if we can make up some simple law or equation ("a model") which does a reasonable job.

What should the friction force depend on?

- Speed?

1. Yes
2. No

Let's try it…

- As a rough approximation - no - the friction force does not depend on the relative speed.

Contact Area?

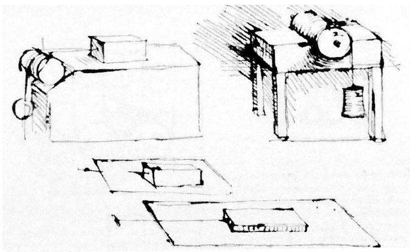
- Does the friction force depend on the contact area?

1. Yes
2. No

Let's try it

- Curiously enough - the friction force does not seem to depend much on the contact area.
- Not what most people expect - but it seems to be roughly true in many cases.
- (though not all cases - wide tires are used on off-road cars and bikes precisely to increase friction on loose surfaces).

Leonardo da Vinci was first to notice this…



Standard Model

- When you push something gently sideways, the friction force will be equal and opposite to the force trying to slide the object along, and will prevent motion.
- The harder you push, the harder friction pushes back - no motion takes place until…

Critical force…

$$f_{\max} \approx \mu_s F_n$$

- Once the net force trying to slide the object along exceeds this critical value, friction can no longer prevent motion.
- F_n is the force normal (perpendicular) to the surface, and μ_s is the coefficient of static friction.

Once something is sliding

$$f_{friction} \approx \mu_d F_n$$

- Where F_n is the force normal (perpendicular) to the surface, and μ_d is the coefficient of dynamic friction.
- The coefficient of dynamic friction is less than the coefficient of static friction.

That's the most widely used model.

- It's actually not very accurate at all.
- Our textbook uses a simpler model - in which the static and dynamic coefficients of friction are identical.
- That model isn't very accurate either - but it is simpler.
- If friction is really important in a given situation - don't use either model - measure the friction experimentally.
- But if it's not crucial - either of these models is a reasonable approximation. If this course - use the textbook model unless specifically told otherwise.

Pushing question

- Imagine that you are pulling a table across the floor. You are applying a constant horizontal force, and as a result, the table is moving at a constant speed v_0.
- The constant horizontal force you are applying…

1. Has the same magnitude as the weight of the box
2. Is greater than the weight of the box
3. Has the same magnitude as the total force that resists the motion of the box
4. Is greater than the total force that resists the motion of the box
5. Is greater than either the weight of the box of the total force that resists its motion.

It's the same

- The table is not accelerating, so the net force in the direction of motion must be zero.
- So the friction force must be equal and opposite to the pushing force.

Double the force

- But what happens if you double the pulling force?
- The box moves…

1. With a constant speed which is double the speed v_o from the previous question.
- With a constant speed which is greater than v_0 but not twice as great.
- For a while with a speed that is constant and greater than v_o, then with a speed that increases thereafter.
- For a while with an increasing speed, then with a constant speed thereafter.
- With a continuously increasing speed.

If you believe our friction model…

- The friction is independent of the speed.
- So when you increase the pulling force, the friction force does not increase.
- That means there will be a constant net force on the table, which will make it accelerate continuously.
- In practice, you can't pull this fast without tripping over - and if you got really fast, air resistance would come into play…

Drag

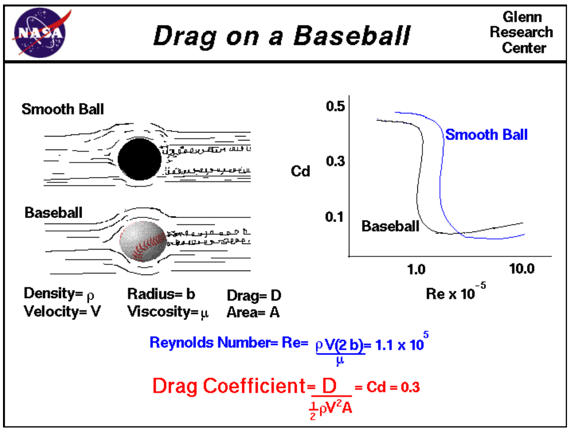
- This occurs when a solid object moves through a fluid (gas or liquid).
- Basically it is the force needed to shove away the fluid in front of the object.

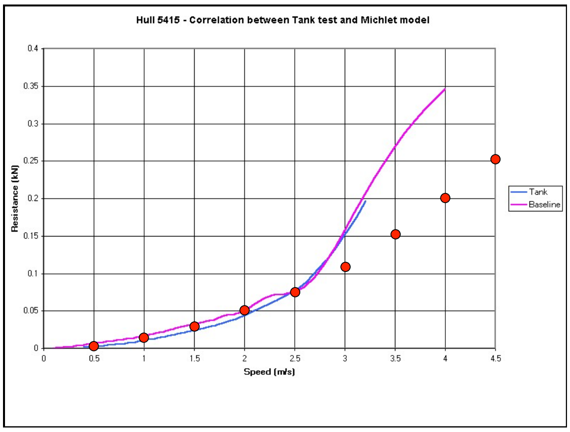
Drag (wind or water resistance) is quite different

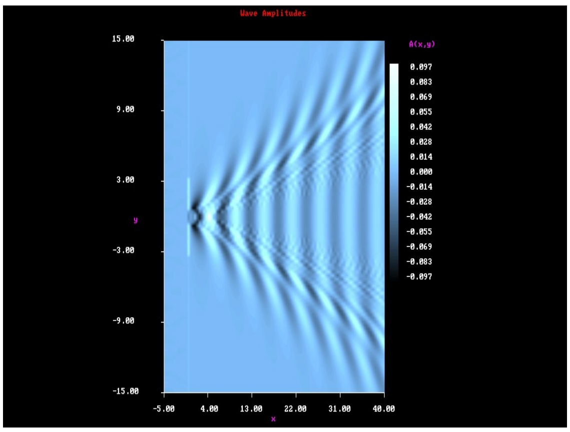
- It increases as something moves faster.
- It's typically assumed to increase as the square of the speed:

$$F_{drag} \approx \frac{1}{2} C \rho A v^2$$

- where C is the drag coefficient, ρ is the density, A the cross sectional area and v the velocity.
- Once again - this is not a very good approximation…







So if drag really matters to you

- (for example, if you are an aerospace or naval engineer) don't trust this simple model - use a (much) more complex one or use experiments…

Conclusions

- Whenever something touches something else, there is a force.
- This force is tricky.
- Normal forces are just enough to stop an object sinking into the surface.
- Various models can be used for friction - it doesn't depend on speed or surface area in these models.
- Drag depends very strongly on relative speed - it can be very complex.