Text mining and Sentiment analysis of Sephora skincare reviews

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Introduction

Purpose of the project

In this project we would like to investigate how consumers talk about beauty products and how this language relates to their ratings and satisfaction. The primary purpose is to apply text mining and NLP methods to customer-written reviews in order to identify dominant themes, sentiment patterns, and recurring concerns, and to assess whether textual features can help explain or predict star ratings across different brands, product types, and price segments. A secondary goal is to use this real-world dataset as a case study for comparing alternative NLP approaches to sentiment or rating prediction in a commercial context.

Main assumptions

This analysis is based on a few simple assumptions.

1. It assumes that most customer reviews are honest and reflect real experiences with the products, so fake or unusual reviews do not change the overall picture.
2. It assumes that the star rating is a good summary of how satisfied the customer is, and that the tone of the review text usually matches the number of stars.
3. It assumes that this dataset gives a fairly accurate overview of Sephora's skincare products and customers, without major gaps or biases caused by how the data was collected.
4. It assumes that the review text contains enough clear and usable information for text analysis, and that the product information linked to each review has been recorded correctly.

Loading libraries

In [86]:
```
# !pip install textblob
# !pip install matplotx
# !pip install vaderSentiment
# !pip install emoji
import matplotx
import pandas as pd
import numpy as np
```

```python
import os
import joblib
import nltk
from nltk.corpus import stopwords
from nltk.tokenize import word_tokenize, sent_tokenize
from nltk.stem import WordNetLemmatizer
from nltk.util import ngrams
from textblob import TextBlob
import re
import string
from collections import Counter
from sklearn.feature_extraction.text import TfidfVectorizer
from sklearn.cluster import MiniBatchKMeans
from sklearn.decomposition import PCA
from sklearn.manifold import TSNE
from sklearn.model_selection import train_test_split
from sklearn.linear_model import LogisticRegression
from sklearn.ensemble import RandomForestClassifier
from sklearn.svm import SVC
from sklearn.utils.class_weight import compute_sample_weight
from sklearn.metrics import classification_report, confusion_matrix, accurac
from vaderSentiment.vaderSentiment import SentimentIntensityAnalyzer
import matplotlib.pyplot as plt
import matplotlib.cm as cm
import matplotlib.patches as mpatches
import matplotx
import seaborn as sns
from wordcloud import WordCloud
import warnings
import emoji
import unicodedata
from sklearn.preprocessing import StandardScaler
from scipy.sparse import hstack
warnings.filterwarnings('ignore')
pd.set_option('display.max_columns', None)
pd.set_option('display.max_colwidth', 100)
from sklearn.metrics import (
    accuracy_score,
    precision_score,
    recall_score,
    f1_score,
    confusion_matrix,
    classification_report,
    roc_auc_score,
    make_scorer
)
from sklearn.metrics import precision_recall_curve, average_precision_score
from sklearn.metrics import roc_curve, auc
from sklearn.metrics import ConfusionMatrixDisplay
from sklearn.model_selection import GridSearchCV, StratifiedKFold, Randomize
from sklearn.svm import LinearSVC
```

In [2]:

```python
nltk_resources = ['punkt', 'punkt_tab', 'stopwords', 'wordnet', 'averaged_pe
for resource in nltk_resources:
    try:
        nltk.data.find(f'tokenizers/{resource}')
```

```python
    except LookupError:
        nltk.download(resource)
```

```
[nltk_data] Downloading package stopwords to
[nltk_data]     /Users/Weronika/nltk_data...
[nltk_data]   Package stopwords is already up-to-date!
[nltk_data] Downloading package wordnet to
[nltk_data]     /Users/Weronika/nltk_data...
[nltk_data]   Package wordnet is already up-to-date!
[nltk_data] Downloading package averaged_perceptron_tagger to
[nltk_data]     /Users/Weronika/nltk_data...
[nltk_data]   Package averaged_perceptron_tagger is already up-to-
[nltk_data]       date!
[nltk_data] Downloading package maxent_ne_chunker to
[nltk_data]     /Users/Weronika/nltk_data...
[nltk_data]   Package maxent_ne_chunker is already up-to-date!
[nltk_data] Downloading package words to /Users/Weronika/nltk_data...
[nltk_data]   Package words is already up-to-date!
```

Data

The dataset consists of Sephora skincare products and customer reviews collected through web scraping in year 2025. The original author used a Python-based web scraper to extract data directly from Sephora's website, specifically targeting the JSON-LD structured data embedded in product pages to minimize parsing errors and ensure data reliability. This scraping approach captured two main components: product-level information (over 8,000 beauty products) and customer review data (approximately 1 million reviews from the skincare category). The dataset includes two primary CSV files: Product and Review datasets.

The author conducted systematic data cleaning to produce an analysis-ready dataset suitable for text mining and NLP tasks. The cleaning workflow included several key steps, specifically for Product data cleaning:

1. Removed products without review information.
2. Preserved multi-label duplicates intentionally. Since the same product can belong to multiple marketing labels, the author retained one row per unique combination of name, brand, category, and label, allowing users to analyze products by label without losing membership information.
3. Fixed scraping inconsistencies that were corrected case-by-case by normalizing price, rating, and review count.
4. Dropped the "best rating" column because it contained only a single value (5.0) across all products.

And for the Reviews data cleaning:

1. Missing review titles (20.6% of reviews) were imputed with empty strings to maintain consistent text fields. Reviews missing the actual text field (0.12% of data)

were dropped entirely.
2. For products with variants (mini sizes or refills), the author aligned the "item_reviewed" field in reviews to match canonical product names in the product table, ensuring accurate joins.

Then, the two datasets were joined on product name and label, creating a unified table where each row represents one review with attached product metadata. Additionally, the author concatenated the review title and text into a single "full_review" field. The author is also applied sentiment scoring, however, our aim is to investigate the data by ourselves. So, we will drop these columns.

The following columns now in the cleaned Product-Review dataset:

review_id - Unique identifier assigned to each review;
date_published - Date the review was posted;
rating_value - Star rating given by the reviewer (1–5);
title - Review title provided by the user (may be empty);
text - Main body of the review;
label - Marketing category under which the product was scraped (Clean, Planet Aware, Vegan, Cruelty-Free, Luxury);
name - Name of the skincare product as listed on Sephora;
brand - Brand or manufacturer of the product;
category - Sephora product category (e.g., Moisturizer, Cleanser);
description - Short marketing or product description from the page;
price - Listed retail price;
currency - Currency the price is listed in;
review_count - Total number of reviews for the product;
aggregate_rating - Average star rating for the product (1–5);
full_review - Merged title with text field;
sentiment - produced sentiment by author;
polarity_score - produced polarity by author;

For this text mining course project, we will use the author's cleaned dataset (combined_product_review_data.csv) as the starting point, which saves substantial preprocessing effort and ensures data quality.

Before proceeding with text mining, we will conduct our own exploratory data analysis to verify data quality, check for any remaining inconsistencies, examine the distribution of ratings and review lengths, and understand the characteristics of the text corpus. We will document any additional preprocessing steps we perform (text normalization, stopword removal, tokenization) to ensure reproducibility and methodological rigor for the course project.

In [3]:
```
df = pd.read_csv("combined_product_review_data.csv")
print(df.head(5))
```

```
print(df.shape)
```

```
   review_id date_published  rating_value                             title  \
0  351645103     2025-07-10           3.0  This lip balm is a miss for me
1  349938731     2025-06-17           5.0                              NaN
2  348900301     2025-06-08           5.0                              NaN
3  347053222     2025-05-24           4.0               amazing… at times
4  346825636     2025-05-21           3.0                        It’s okay


text  \
0  It’s much thinner than I thought it would be and the hydration doesn’t la
st very long. The flavo...
1  Consistency is a great mix between a balm and an oil! My issue with a lot
of the new “lip oil” p...
2  As someone who never writes reviews, I HAD TO for this product! It is abs
olutely amazing. Moistu...
3  i’m lucky enough to have tried multiple tubes of this product. there seem
s to be a difference in...
4  It’s not good or bad, just in the middle. It doesn’t plump my lips at all
and it doesn’t really ...

   label                                              name  brand  \
0  clean  Plumping & Softening Sweet Agave Lip Balm Treatment  ALPYN
1  clean  Plumping & Softening Sweet Agave Lip Balm Treatment  ALPYN
2  clean  Plumping & Softening Sweet Agave Lip Balm Treatment  ALPYN
3  clean  Plumping & Softening Sweet Agave Lip Balm Treatment  ALPYN
4  clean  Plumping & Softening Sweet Agave Lip Balm Treatment  ALPYN

            category  \
0  lip-balm-lip-care
1  lip-balm-lip-care
2  lip-balm-lip-care
3  lip-balm-lip-care
4  lip-balm-lip-care


description  \
0  Shop ALPYN’s Willow & Sweet Agave Plumping Lip Mask at Sephora. This mask
has sweet agave and hy...
1  Shop ALPYN’s Willow & Sweet Agave Plumping Lip Mask at Sephora. This mask
has sweet agave and hy...
2  Shop ALPYN’s Willow & Sweet Agave Plumping Lip Mask at Sephora. This mask
has sweet agave and hy...
3  Shop ALPYN’s Willow & Sweet Agave Plumping Lip Mask at Sephora. This mask
has sweet agave and hy...
4  Shop ALPYN’s Willow & Sweet Agave Plumping Lip Mask at Sephora. This mask
has sweet agave and hy...

   price currency  review_count  aggregate_rating  \
0   28.0      USD         291.0          4.457045
1   28.0      USD         291.0          4.457045
2   28.0      USD         291.0          4.457045
3   28.0      USD         291.0          4.457045
4   28.0      USD         291.0          4.457045


full_review  \
```

```
0  This lip balm is a miss for me It’s much thinner than I thought it would
be and the hydration do...
1  Consistency is a great mix between a balm and an oil! My issue with a lot
of the new “lip oil” p...
2  As someone who never writes reviews, I HAD TO for this product! It is abs
olutely amazing. Moistu...
3  amazing… at times i’m lucky enough to have tried multiple tubes of this p
roduct. there seems to ...
4  It’s okay It’s not good or bad, just in the middle. It doesn’t plump my l
ips at all and it doesn...

  sentiment  polarity_score
0  negative         -0.0772
1  positive          0.1260
2  positive          0.8135
3  positive          0.9744
4  positive          0.3278
(40234, 17)
```

In [4]:
```
# drop title and text, since full_review contains this information
# drop sentiment and polarity since they were produced by author
df = df.drop(columns = ['title', 'text', 'sentiment', 'polarity_score'])
```

In [5]:
```
df.nunique()
```

Out[5]:
```
review_id           18556
date_published       1501
rating_value            5
label                   5
name                 2011
brand                 171
category               85
description          1948
price                 315
currency                1
review_count          949
aggregate_rating     1754
full_review         18765
dtype: int64
```

We can see that we have 40,234 entries, but only 18765 unique reviews. It could be because the author saved multi-label reviews and kept entries by unique name, brand, category, and label, and, as a result, the same review could apper multiple times if the product belongs to multiple marketing categories (labels). Another assumption that some reviews, if they are short, just a simple words like "nice", "love it", "hate it", ect. Lets check our assumptions.

In [6]:
```
# Lets check the distribution of the reviews
dupl_counts = df.groupby('full_review').size().reset_index(name='count')
dupl_counts = dupl_counts[dupl_counts['count'] > 1].sort_values('count', asc

print(f"\nDistribution of duplicate reviews:")
print(dupl_counts['count'].value_counts().sort_index())
print("Why the same review appears multiple times")
```

```python
# Pick a review that appears many times
sample_full_review = dupl_counts.iloc[0]['full_review']
sample_df = df[df['full_review'] == sample_full_review][['review_id', 'name'

print(f"\nReview ID: {sample_df['review_id'].iloc[0]}")
print(f"Review text (first 100 chars): {sample_full_review[:100]}...\n")
print(f"This review appears {len(sample_df)} times:\n")
print(sample_df.to_string(index=False))

# What labels does it have?
print(f"\n\nLabels for this review:")
for idx, row in sample_df.iterrows():
    print(f"  - {row['label']}")
```

```
Distribution of duplicate reviews:
count
2     5645
3     3554
4     1615
5      202
6      268
7       43
8      141
10      39
11       2
12       8
20       1
Name: count, dtype: int64
Why the same review appears multiple times

Review ID: 360988607
Review text (first 100 chars): This lotion is such a Beautiful scent. Ultra
hydrating and leaves your skin with a beautiful glow. Y...

This review appears 20 times:

 review_id
name        label      brand
 360988607      Mini The Body Wash Eucalyptus - Nourishing Treatment Cleanse
With Lipid-Rich Oils + Niacinamide        clean Nécessaire
 360988607           The Body Wash Eucalyptus - Nourishing Treatment Cleanse
With Lipid-Rich Oils + Niacinamide        clean Nécessaire
 360989695            The Body Wash Santal – Therapeutic treatment Cleanse W
ith Epsom Salt + Minerals With Pump        clean Nécessaire
 360988607 The Body Wash Eucalyptus - Nourishing Treatment Cleanse With Lipi
d-Rich Oils + Niacinamide With Pump        clean Nécessaire
 360989695                      The Body Wash Santal - Therapeutic Treatment
Cleanse With Epsom Salt + Minerals        clean Nécessaire
 360989695                      The Body Wash Santal - Therapeutic Treatment
Cleanse With Epsom Salt + Minerals cruelty-free Nécessaire
 360989695            The Body Wash Santal – Therapeutic treatment Cleanse W
ith Epsom Salt + Minerals With Pump cruelty-free Nécessaire
 360988607 The Body Wash Eucalyptus - Nourishing Treatment Cleanse With Lipi
d-Rich Oils + Niacinamide With Pump cruelty-free Nécessaire
 360988607           The Body Wash Eucalyptus - Nourishing Treatment Cleanse
With Lipid-Rich Oils + Niacinamide cruelty-free Nécessaire
 360988607      Mini The Body Wash Eucalyptus - Nourishing Treatment Cleanse
With Lipid-Rich Oils + Niacinamide cruelty-free Nécessaire
 360988607           The Body Wash Eucalyptus - Nourishing Treatment Cleanse
With Lipid-Rich Oils + Niacinamide       planet Nécessaire
 360988607      Mini The Body Wash Eucalyptus - Nourishing Treatment Cleanse
With Lipid-Rich Oils + Niacinamide       planet Nécessaire
 360989695                      The Body Wash Santal - Therapeutic Treatment
Cleanse With Epsom Salt + Minerals       planet Nécessaire
 360989695            The Body Wash Santal – Therapeutic treatment Cleanse W
ith Epsom Salt + Minerals With Pump       planet Nécessaire
 360988607 The Body Wash Eucalyptus - Nourishing Treatment Cleanse With Lipi
d-Rich Oils + Niacinamide With Pump       planet Nécessaire
 360988607           The Body Wash Eucalyptus - Nourishing Treatment Cleanse
With Lipid-Rich Oils + Niacinamide        vegan Nécessaire
```

```
 360988607      Mini The Body Wash Eucalyptus – Nourishing Treatment Cleanse
With Lipid-Rich Oils + Niacinamide        vegan Nécessaire
 360988607 The Body Wash Eucalyptus – Nourishing Treatment Cleanse With Lipi
d-Rich Oils + Niacinamide With Pump        vegan Nécessaire
 360989695                       The Body Wash Santal – Therapeutic Treatment
Cleanse With Epsom Salt + Minerals        vegan Nécessaire
 360989695            The Body Wash Santal – Therapeutic treatment Cleanse W
ith Epsom Salt + Minerals With Pump        vegan Nécessaire


Labels for this review:
  - clean
  - clean
  - clean
  - clean
  - clean
  - cruelty-free
  - cruelty-free
  - cruelty-free
  - cruelty-free
  - cruelty-free
  - planet
  - planet
  - planet
  - planet
  - planet
  - vegan
  - vegan
  - vegan
  - vegan
  - vegan
```

Yes, we proved our assumption that reviews were duplicated due to the different labels for one review. It is still usefull for our dataset EDA, however, for the text mining, sentiment analysis, text classification and other tasks that we want to perform with dataset's reviews, we need create a separate dataframe with unique reviews.

In [7]:
```python
df_unique = df.drop_duplicates(subset=['review_id']).copy()

print(f"Shape before: {df.shape}")
print(f"Shape after: {df_unique.shape}")
print(f"Unique review_ids: {df_unique['review_id'].nunique()}")
print(f"Unique full_reviews: {df_unique['full_review'].nunique()}")
```

```
Shape before: (40234, 13)
Shape after: (18556, 13)
Unique review_ids: 18556
Unique full_reviews: 18545
```

In [8]:
```python
dupl_rev_texts = df_unique.groupby('full_review').filter(lambda x: len(x) >

print(f"Total duplicate instances: {len(dupl_rev_texts)}")
print(f"Unique review texts that are duplicated: {dupl_rev_texts['full_revie

dupl_rev_texts_sorted = dupl_rev_texts.sort_values('full_review')[
```

```
    ['review_id', 'date_published', 'rating_value', 'name', 'brand', 'full_r
]

print("Reviews with duplicate text:")
print(dupl_rev_texts_sorted.to_string())
```

```
Total duplicate instances: 19
Unique review texts that are duplicated: 8
Reviews with duplicate text:
       review_id date_published  rating_value
name              brand
full_review
63     354093561     2025-08-11           5.0                    Facial Radi
ance Pads with Glycolic + Lactic Acids – Exfoliating Pads with AHA   First A
id Beauty
A handy product to keep in your wallet – compact, useful, and definitely val
ue for money.
548    354061916     2025-08-11           5.0
Vinopure Acne-Prone Skin Essentials           Caudalie
A handy product to keep in your wallet – compact, useful, and definitely val
ue for money.
3901   344037276     2025-04-19           3.0
Truth Juice™ Gentle Glow Daily Cleanser       OLEHENRIKSEN
Allergic reaction to vitamin C. Skin was red and broken/raw. if you have sen
sitive skin I would be cautious and pay attention before your skin breaks/ra
w from vitamin C reaction.
8756   344037243     2025-04-19           2.0
The Glow Cycle Skincare Set        OLEHENRIKSEN
Allergic reaction to vitamin C. Skin was red and broken/raw. if you have sen
sitive skin I would be cautious and pay attention before your skin breaks/ra
w from vitamin C reaction.
13349  249967811     2023-06-05           2.0
Clarifying Face Cream  Dr. Barbara Sturm
Did Not Work For Me I was so hopeful for this line… I have perioral dermatit
is, aging skin, and prone to breakouts. Unfortunately using this line exclus
ively, I had the worst breakout I have experienced in 10+ years. After three
days of stopping this line completely, my skin has almost completely healed.
Not sure what it is that my skin does not like, but sadly this line did not
work for me.
11969  249967787     2023-06-05           2.0
Clarifying Serum  Dr. Barbara Sturm
Did Not Work For Me I was so hopeful for this line… I have perioral dermatit
is, aging skin, and prone to breakouts. Unfortunately using this line exclus
ively, I had the worst breakout I have experienced in 10+ years. After three
days of stopping this line completely, my skin has almost completely healed.
Not sure what it is that my skin does not like, but sadly this line did not
work for me.
12666  325474237     2024-11-16           1.0
Super Anti-Aging Eye Serum  Dr. Barbara Sturm
Don't waste your money never received product, customer service is horrible.
12050  325474268     2024-11-16           1.0
Super Anti-Aging Eye Cream  Dr. Barbara Sturm
Don't waste your money never received product, customer service is horrible.
10684  316041648     2024-08-06           5.0
Equilibrium™ Restoring Essence          Hourglass  Fantastic 53 year old fem
ale with highly sensitive, eczema prone, allergy suffering skin. I absolutel
y love the essence, serum, both eye creams, and moisturizer. 5 stars for eac
h one. Best line out there. I don't know why there isn't more buzz out there
because this is the best. Skipped the cleanser as it is expensive, subpar in
gredients (especially considering the quality ingredients in the rest of the
line), and you wash it off.
13404  316041697     2024-08-06           5.0
```

Equilibrium™ Restorative Hydrating Cream   Hourglass Fantastic 53 ye
ar old female with highly sensitive, eczema prone, allergy suffering skin. I
absolutely love the essence, serum, both eye creams, and moisturizer. 5 star
s for each one. Best line out there. I don't know why there isn't more buzz
out there because this is the best. Skipped the cleanser as it is expensive,
subpar ingredients (especially considering the quality ingredients in the re
st of the line), and you wash it off.
13358 316041758   2024-08-06   5.0
Equilibrium Instant Plumping Eye Mask   Hourglass Fantastic 53 year
old female with highly sensitive, eczema prone, allergy suffering skin. I ab
solutely love the essence, serum, both eye creams, and moisturizer. 5 stars
for each one. Best line out there. I don't know why there isn't more buzz ou
t there because this is the best. Skipped the cleanser as it is expensive, s
ubpar ingredients (especially considering the quality ingredients in the res
t of the line), and you wash it off.
12529 316041857   2024-08-06   5.0
Equilibrium™ Intensive Hydrating Eye Balm   Hourglass Fantastic 53 y
ear old female with highly sensitive, eczema prone, allergy suffering skin.
I absolutely love the essence, serum, both eye creams, and moisturizer. 5 st
ars for each one. Best line out there. I don't know why there isn't more buz
z out there because this is the best. Skipped the cleanser as it is expensiv
e, subpar ingredients (especially considering the quality ingredients in the
rest of the line), and you wash it off.
42   356910279   2025-09-10   1.0
Mini Barrier Restore Cream Comforting Daily Moisturizer   rhode
Overhyped yt mediocre brand Don’t fall for the Hype! Got the whole kit and t
he lipgloss. Made my lips darker and so dry and my face started breaking out
the first day, but I kept going because they gaslighted me and now it keeps
getting worse…. Now I have a huge acne breakouts and hyperpigmentations.
10002 356910267   2025-09-10   1.0
Mini Peptide Glazing Fluid Dewy Gel Serum   rhode
Overhyped yt mediocre brand Don’t fall for the Hype! Got the whole kit and t
he lipgloss. Made my lips darker and so dry and my face started breaking out
the first day, but I kept going because they gaslighted me and now it keeps
getting worse…. Now I have a huge acne breakouts and hyperpigmentations.
19250 356910263   2025-09-10   1.0
Mini Barrier Butter Intensive Moisture Balm   rhode
Overhyped yt mediocre brand Don’t fall for the Hype! Got the whole kit and t
he lipgloss. Made my lips darker and so dry and my face started breaking out
the first day, but I kept going because they gaslighted me and now it keeps
getting worse…. Now I have a huge acne breakouts and hyperpigmentations.
4887   360989695   2025-10-01   5.0   The Body Wash Santal –
Therapeutic treatment Cleanse With Epsom Salt + Minerals With Pump   N
écessaire
This lotion is such a Beautiful scent. Ultra hydrating and leaves your skin
with a beautiful glow. You don’t need much at all. Body wash is very fresh a
nd sophisticated scent. Leaves my skin feeling soft and hydrated. Both smell
s amazing.
52   360988607   2025-10-01   5.0 Mini The Body Wash Eucalyptus
– Nourishing Treatment Cleanse With Lipid-Rich Oils + Niacinamide   Né
cessaire
This lotion is such a Beautiful scent. Ultra hydrating and leaves your skin
with a beautiful glow. You don’t need much at all. Body wash is very fresh a
nd sophisticated scent. Leaves my skin feeling soft and hydrated. Both smell
s amazing.
9889   361924686   2025-10-14   5.0

```
VinoHydra Sorbet Cream Moisturizer with Hyaluronic Acid           Caudalie
You can't miss it in your skincare routine! I'm loving my new Vinohydra Deep
Moisturizer cream, because it leaves my skin super hydrated since I always s
truggle with the dryness of my skin. It has a subtle and pleasant smell, its
texture is super soft and not heavy at all, ready to do your makeup.
27179  361925069     2025-10-14           5.0
VinoHydra Deep Hydration Moisturizer           Caudalie
You can't miss it in your skincare routine! I'm loving my new Vinohydra Deep
Moisturizer cream, because it leaves my skin super hydrated since I always s
truggle with the dryness of my skin. It has a subtle and pleasant smell, its
texture is super soft and not heavy at all, ready to do your makeup.
```

After detailed consideration, we can see that remaining duplicates actually are not duplicates. Seems like one review spreaded for several different products, probably, that were bought all at once. So, we can keep these duplicated reviews since they are desribe different products and the share of the remaining unique reviews is small.

In [9]:

```
print("Missing values:")
print(df_unique.isnull().sum())

print("\nBasic Statistics:")
print(df_unique.describe())
```

```
Missing values:
review_id          0
date_published     0
rating_value       0
label              0
name               0
brand              0
category           0
description        0
price              0
currency           0
review_count       0
aggregate_rating   0
full_review        0
dtype: int64

Basic Statistics:
          review_id  rating_value         price  review_count  \
count  1.855600e+04  18556.000000  18556.000000  18556.000000
mean   3.336313e+08      3.891302     55.266561    594.809064
std    4.124094e+07      1.505613     61.630170   1175.509794
min    9.176823e+06      1.000000      0.010000      1.000000
25%    3.310596e+08      3.000000     25.000000     98.000000
50%    3.497116e+08      5.000000     38.000000    257.000000
75%    3.563784e+08      5.000000     60.000000    593.000000
max    3.621667e+08      5.000000    699.000000  21772.000000

       aggregate_rating
count      18556.000000
mean           4.352683
std            0.404575
min            1.000000
25%            4.165138
50%            4.430723
75%            4.634615
max            5.000000
```

As we can see, there are no null values in any of the remaining columns. Regarding the basic statistics, we observe that rating_value (individual review ratings) and aggregate_rating (product-level average ratings) ranges from approximately 1 to 5. Product prices span from 0.01 to 699 USD, and the number of reviews per product varies considerably, ranging from 1 to 21,772 reviews. There is no need to work with numeric variables now.

In this preprocessing step, lets also add binary rating variable. In e-commerce settings, written reviews are typically left for strongly positive or strongly negative experiences. Truly neutral experiences are under-represented. Ratings of 4 and 5 generally correspond to clear satisfaction, whereas 1–3 indicate dissatisfaction or at best ambivalent evaluations, so merging them into two classes reflects how business and users actually interpret the scale.

In [10]:
```
# Lets add for the both dataframes (original and with unique reviews). We wi

df['rating_binary'] = df['rating_value'].apply(lambda x: 1 if x >= 4 else 0)
df['rating_category'] = df['rating_value'].apply(lambda x: 'Positive' if x >
print(f"\nRating distribution (original reviews df):")
print(df['rating_category'].value_counts())


df_unique['rating_binary'] = df_unique['rating_value'].apply(lambda x: 1 if
df_unique['rating_category'] = df_unique['rating_value'].apply(lambda x: 'Po
print(f"\nRating distribution (unique reviews df):")
print(df_unique['rating_category'].value_counts())
```

```
Rating distribution (original reviews df):
rating_category
Positive    27938
Negative    12296
Name: count, dtype: int64

Rating distribution (unique reviews df):
rating_category
Positive    12874
Negative     5682
Name: count, dtype: int64
```

We also can see now that we need to work with imbalanced dataset, since number of the positive reviews is 12874 (for the unique reviews dataset) and number of the negative reviews is 5682.

Text Preprocessing

Cleaning, tokenization, and lemmatization

The next step is to design of the preprocessing class. Firstly, we need to convert text to lowercase, remove different characters (emojis), punctuation, and normalise digits in the text. Then remove tokens that carry little or no sentiment signal for product reviews (links, order numbers, etc.). Additionaly, we need to collapse multiple spaces to a single space to keep the representation compact while preserving token order.

Secondly, using NLTK word_tokenize splits text into linguistically meaningful tokens rather than naive whitespace splitting, which improves downstream vectorisation. Next, removing English stop-words and tokens of length ≤ 2 reduces very high-frequency but low-information words (like "the", "and", "to") and stray characters, which typically improves both sparsity and model performance in sentiment tasks. Then, lemmatizing with WordNetLemmatizer maps inflected forms to their base form, which reduces vocabulary size and helps the model generalise across morphological variants.

In [11]:
```
class TextPreprocessor:
    def __init__(self, remove_stopwords=True, min_token_length=2):
```

```python
        self.lemmatizer = WordNetLemmatizer()
        self.stop_words = set(stopwords.words('english')) if remove_stopword
        self.min_token_length = min_token_length

    def clean_text(self, text):
        if pd.isna(text) or text == "":
            return ""

        text = text.lower()
        # Remove URLs
        text = re.sub(r'http\S+|www\S+|https\S+', '', text, flags=re.MULTILI
        # Remove email addresses
        text = re.sub(r'\S+@\S+', '', text)
        # Remove emojis
        text = emoji.replace_emoji(text, replace='')
        # Remove numbers
        text = re.sub(r'\d+', '', text)
        # Remove standard ASCII punctuation
        text = text.translate(str.maketrans('', '', string.punctuation))
        # Remove additional Unicode punctuation and special characters (elli
        text = re.sub(r'[^\w\s]', '', text)
        # Normalize Unicode characters
        text = unicodedata.normalize('NFKD', text)
        text = text.encode('ascii', 'ignore').decode('utf-8')
        text = ' '.join(text.split())
        return text

    def tokenize_and_lemmatize(self, text):
        if not text:
            return []

        tokens = word_tokenize(text)
        lemmatized = [
            self.lemmatizer.lemmatize(token)
            for token in tokens
            if token not in self.stop_words
            and len(token) > self.min_token_length
            and token.isalpha()  # Keep only alphabetic tokens
        ]
        return lemmatized # Returns list of processed tokens

    # Full pipeline: clean, tokenize, lemmatize, and join back to string.
    def get_processed_text(self, text):
        cleaned = self.clean_text(text)
        tokens = self.tokenize_and_lemmatize(cleaned)
        return ' '.join(tokens)


# Initialize preprocessor
preprocessor = TextPreprocessor(remove_stopwords=True, min_token_length=2)
```

In [12]:

```python
df_unique['cleaned_review'] = df_unique['full_review'].apply(preprocessor.cl
df_unique['processed_review'] = df_unique['full_review'].apply(preprocessor.

print("Text preprocessing complete!")
```

```python
idx = 5
print(f"Original: {df_unique.loc[idx, 'full_review'][:200]}...")
print(f"\nCleaned: {df_unique.loc[idx, 'cleaned_review'][:200]}...")
print(f"\nProcessed: {df_unique.loc[idx, 'processed_review'][:200]}...")
```

```
Text preprocessing complete!
Original: So much for sustainable packaging… Originally bought this about a
year, maybe two, ago when it was a sephora online only brand. Marketed as a
smaller sustainable clean beauty brand, even their 100 poi...

Cleaned: so much for sustainable packaging originally bought this about a ye
ar maybe two ago when it was a sephora online only brand marketed as a small
er sustainable clean beauty brand even their point sample...

Processed: much sustainable packaging originally bought year maybe two ago s
ephora online brand marketed smaller sustainable clean beauty brand even poi
nt sample tester packaged metal definitely pricier side did...
```

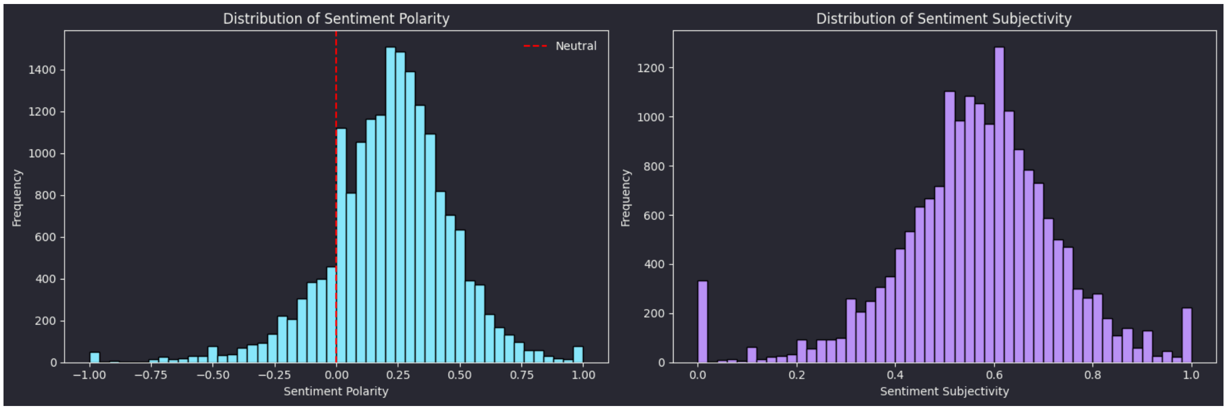
Sentiment analysis

In [13]:
```python
# Get sentiment polarity and subjectivity using TextBlob
def get_sentiment(text):
    blob = TextBlob(str(text))
    return blob.sentiment.polarity, blob.sentiment.subjectivity

print("Performing sentiment analysis...")
sentiments = df_unique['full_review'].apply(get_sentiment)
df_unique['sentiment_polarity'] = sentiments.apply(lambda x: x[0])
df_unique['sentiment_subjectivity'] = sentiments.apply(lambda x: x[1])

print("Sentiment analysis complete!")
print(f"\nAverage Sentiment Polarity: {df_unique['sentiment_polarity'].mean(
print(f"Average Sentiment Subjectivity: {df_unique['sentiment_subjectivity']
print(f"Correlation (Sentiment vs Rating): {df_unique['sentiment_polarity'].
```

```
Performing sentiment analysis...
Sentiment analysis complete!

Average Sentiment Polarity: 0.217
Average Sentiment Subjectivity: 0.566
Correlation (Sentiment vs Rating): 0.527
```

In [14]:
```python
plt.style.use(matplotx.styles.dracula)
fig, axes = plt.subplots(1, 2, figsize=(15, 5))

# Polarity
axes[0].hist(df_unique['sentiment_polarity'], bins=50, color = '#8be9fd', ec
axes[0].axvline(x=0, color='red', linestyle='--', label='Neutral')
axes[0].set_xlabel('Sentiment Polarity')
axes[0].set_ylabel('Frequency')
axes[0].set_title('Distribution of Sentiment Polarity')
axes[0].legend()

axes[1].hist(df_unique['sentiment_subjectivity'], bins=50, color='#bd93f9',
axes[1].set_xlabel('Sentiment Subjectivity')
```

```python
axes[1].set_ylabel('Frequency')
axes[1].set_title('Distribution of Sentiment Subjectivity')

plt.tight_layout()
plt.show()
```



The average sentiment polarity of 0.217 indicates that Sephora reviews are moderately positive overall. However, we can notice the polarity range from -1 (extremely negative) to +1(extremely positive). We can notice that 0.217 is just slight shift from the neutral to positive review. And we also can explain it by typical customer behavior, where buyers are selective about what they purchase and more likely to leave reviews for products they have opinions about (strong positive or negative).

We can observe the normal or near-normal, slightly right-skewed distribution on both histogram plots. The broad distribution reflects that Sephora carries thousands of products with varying quality, price points, and suitability for different skin types—customers express nuanced opinions. There's no single dominant sentiment because reviews are spread across the spectrum rather than clustered at +1.0 or -1.0. Taking precisely into consideration subjectivity plot, we can see that reviews are slightly more opinion-based than fact-based. So, it means that customers use evaluative language ("amazing," "terrible," "works for me") rather than pure description (like "containing aroma, glycerin", ect.). This again supports "healthy" behavior regarding products reviews, where customers share personal experiences and judgments.

EDA

Text statistics

In [15]:
```python
# Calculate various text statistics from review text
def calculate_text_stats(text):
    if pd.isna(text) or text == "":
        return 0, 0, 0, 0, 0

    # Tokenize and filter to alphabetic words only
    all_tokens = word_tokenize(str(text))
    words = [w for w in all_tokens if w.isalpha()]
    sentences = sent_tokenize(str(text))
```

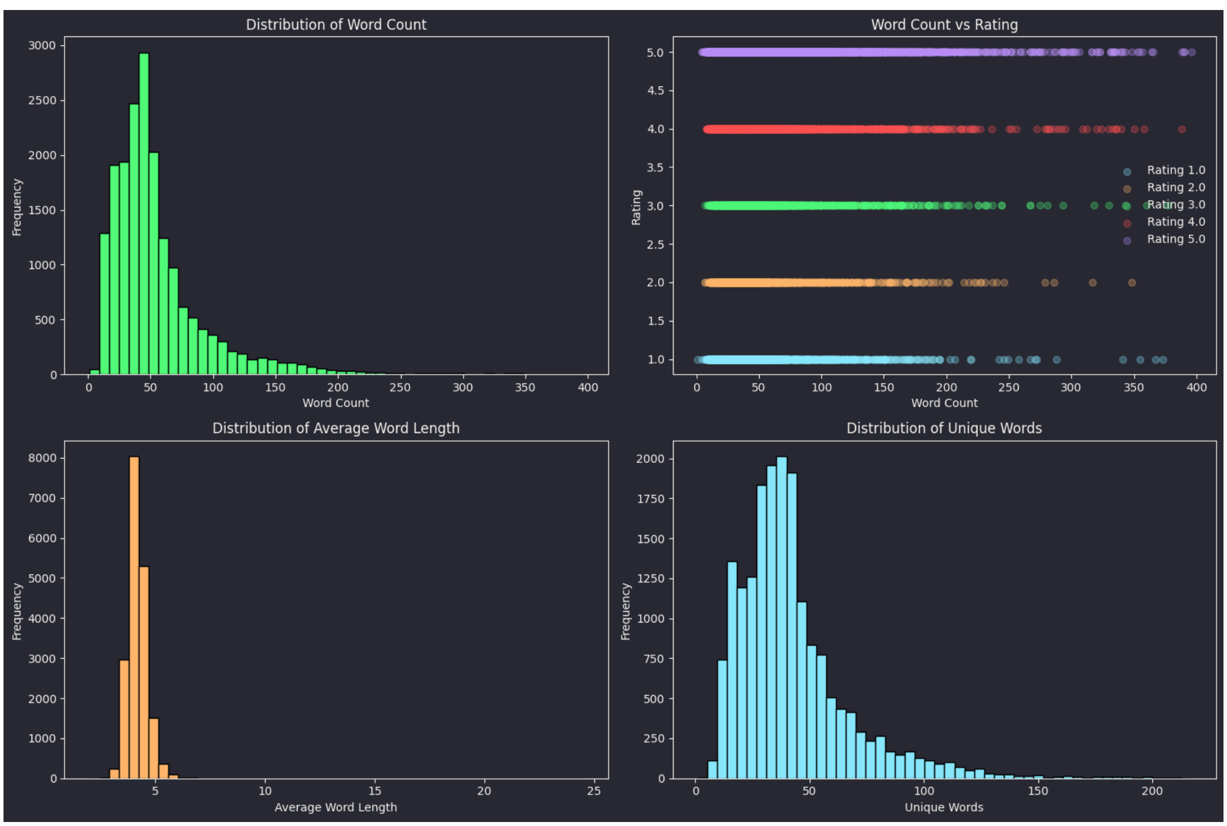
```python
    return (
        len(words),
        len(text),
        len(sentences),
        np.mean([len(word) for word in words]) if words else 0,
        len(set(words))
    )

print("Calculating text statistics...")
text_stats = df_unique['full_review'].apply(calculate_text_stats)

df_unique['word_count'] = text_stats.apply(lambda x: x[0])
df_unique['char_count'] = text_stats.apply(lambda x: x[1])
df_unique['sentence_count'] = text_stats.apply(lambda x: x[2])
df_unique['avg_word_length'] = text_stats.apply(lambda x: x[3])
df_unique['unique_words'] = text_stats.apply(lambda x: x[4])

print("\nText Statistics Summary:")
print(df_unique[['word_count', 'char_count', 'sentence_count', 'avg_word_ler
```

```
Calculating text statistics...

Text Statistics Summary:
         word_count    char_count  sentence_count  avg_word_length  \
count  18556.000000  18556.000000    18556.000000     18556.000000
mean      55.108321    296.882302        4.224617         4.181720
std       41.348956    230.427676        2.610282         0.460577
min        1.000000     38.000000        1.000000         2.000000
25%       30.000000    161.000000        3.000000         3.893939
50%       45.000000    237.000000        4.000000         4.139535
75%       65.000000    344.000000        5.000000         4.418605
max      396.000000   2048.000000       29.000000        24.500000

       unique_words
count  18556.000000
mean      42.455109
std       25.307152
min        1.000000
25%       26.000000
50%       37.000000
75%       50.000000
max      217.000000
```

The Sephora review corpus comprises 18,556 unique reviews with a mean length of 55 words (SD = 41.3), organized into an average of 4.2 sentences. Reviews exhibit high lexical diversity (77% unique words per review), indicating authentic, user-generated content. The average word length of 4.18 characters suggests accessible, everyday language rather than technical terminology. The distribution is right-skewed, with most reviews ranging from 30-65 words, though some highly engaged customers submit detailed 300+ word assessments. We can notice that these characteristics are also consistent with mobile e-commerce review.

In [16]:

```
plt.style.use(matplotx.styles.dracula)
fig, axes = plt.subplots(2, 2, figsize=(15, 10))

axes[0, 0].hist(df_unique['word_count'], bins=50, color='#50fa7b', edgecolor
axes[0, 0].set_xlabel('Word Count')
axes[0, 0].set_ylabel('Frequency')
axes[0, 0].set_title('Distribution of Word Count')

for rating in sorted(df_unique['rating_value'].unique()):
    subset = df_unique[df_unique['rating_value'] == rating]
    axes[0, 1].scatter(subset['word_count'], subset['rating_value'], alpha=0
axes[0, 1].set_xlabel('Word Count')
axes[0, 1].set_ylabel('Rating')
axes[0, 1].set_title('Word Count vs Rating')
axes[0, 1].legend()

axes[1, 0].hist(df_unique['avg_word_length'], bins=50, color='#ffb86c', edge
axes[1, 0].set_xlabel('Average Word Length')
axes[1, 0].set_ylabel('Frequency')
axes[1, 0].set_title('Distribution of Average Word Length')

axes[1, 1].hist(df_unique['unique_words'], bins=50, color='#8be9fd', edgecol
axes[1, 1].set_xlabel('Unique Words')
axes[1, 1].set_ylabel('Frequency')
axes[1, 1].set_title('Distribution of Unique Words')

plt.tight_layout()
plt.show()
```



The Word count distribution (top left) histogram is right-skewed. Most reviews fall between roughly 20 and 80 words, with a long tail up to nearly 400 words. This confirms that the typical review is concise (a short paragraph), while a minority of users write very long, detailed reviews, which pull the mean above the median.

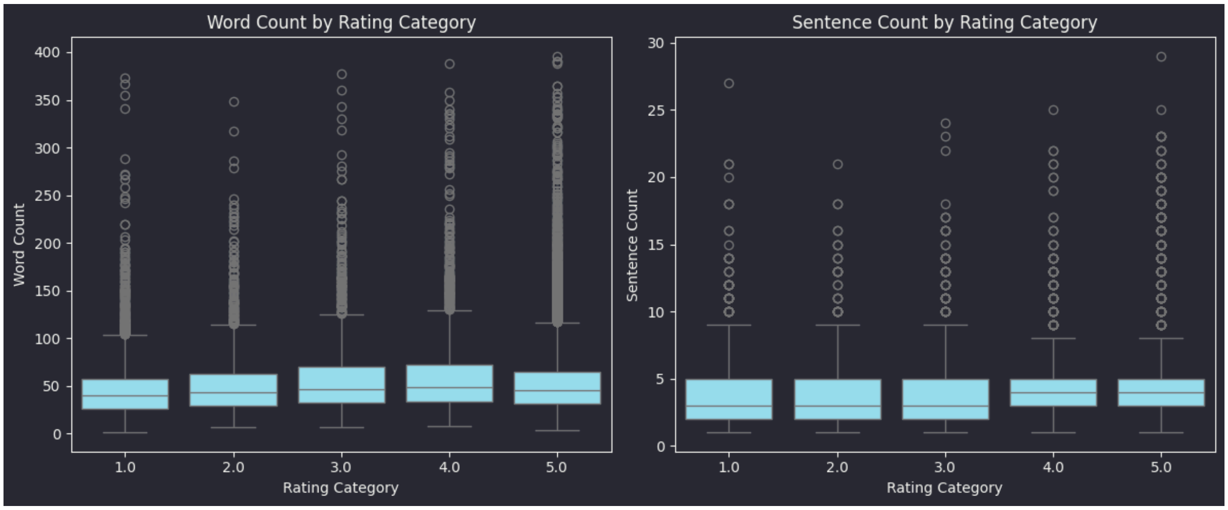
Word count vs rating (top right) plot shows that ratings are clearly discrete at 1–5, and for each rating there is a wide spread of word counts, mostly between about 20 and 150 words. There is no strong visual pattern that higher ratings are systematically longer or shorter. Very short and very long reviews exist at all rating levels, which suggests that review length alone is not a strong driver of rating.

Average word length distribution (bottom left) displays that average word length is tightly concentrated around 4–4.5 characters, with almost all reviews in a narrow band from about 3.5 to 5. This again indicates that reviewers use simple, everyday vocabulary, which is good for readability and suggests the text is accessible and not overly technical.

Unique words distribution (bottom right) per review peaks around 30–50 and is right-skewed, extending beyond 150 unique words in a few long reviews. Compared to the total word count distribution, this implies a high proportion of unique tokens per review, so the language is not highly repetitive and the corpus offers good lexical diversity.

In [17]:

```
# Length vs rating / sentiment
plt.figure(figsize=(12, 5))

plt.subplot(1, 2, 1)
sns.boxplot(data=df_unique, x='rating_value', y='word_count', color='#8be9fc
plt.title('Word Count by Rating Category')
plt.xlabel('Rating Category')
plt.ylabel('Word Count')

plt.subplot(1, 2, 2)
sns.boxplot(data=df_unique, x='rating_value', y='sentence_count', color='#8b
plt.title('Sentence Count by Rating Category')
plt.xlabel('Rating Category')
plt.ylabel('Sentence Count')

plt.tight_layout()
plt.show()

print(df_unique.groupby('rating_value')[['word_count', 'sentence_count']].de
```



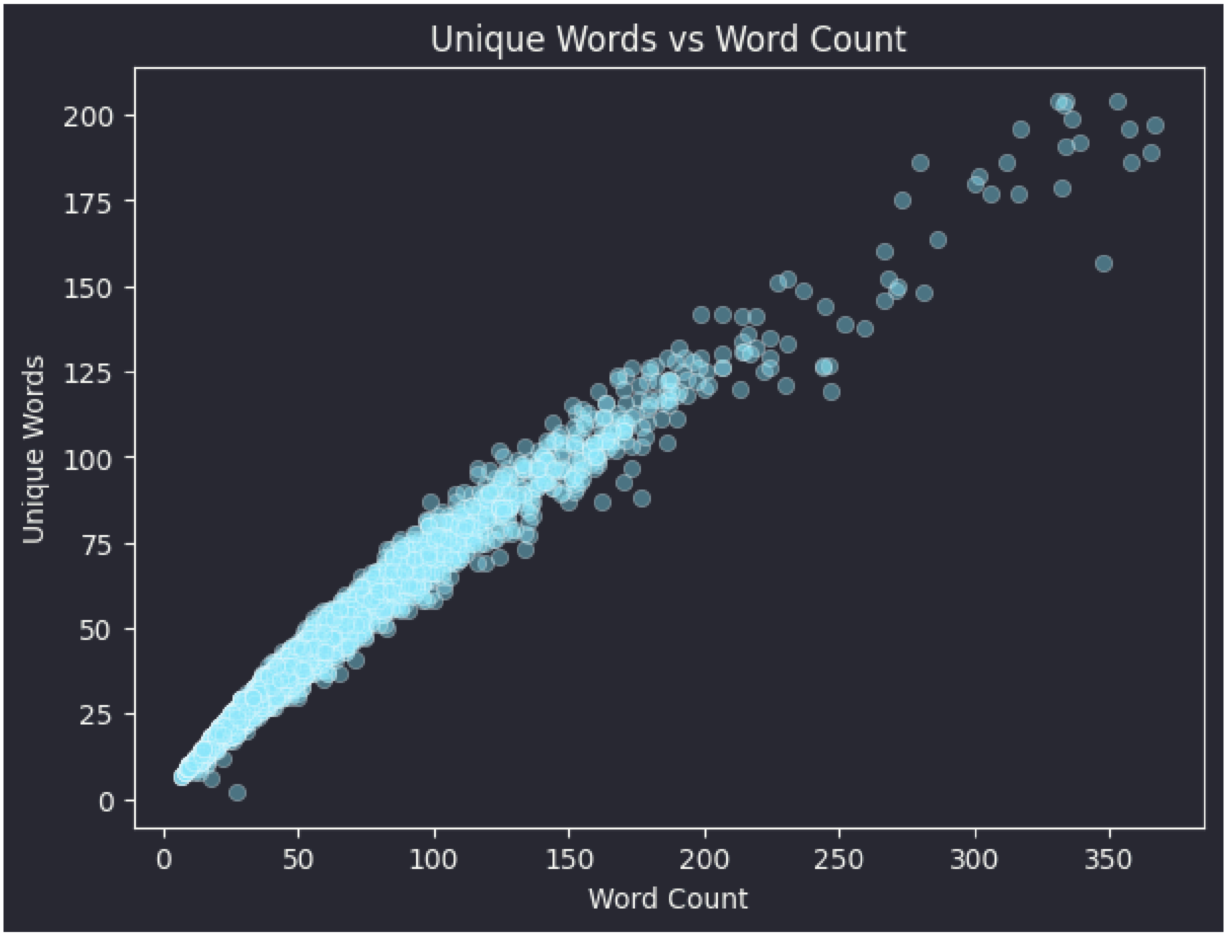

```
             word_count
\
                  count       mean        std  min   25%   50%   75%    max
rating_value
1.0              2705.0  48.173013  35.732327  1.0  26.0  40.0  57.0  373.0
2.0              1471.0  52.733515  38.229005  7.0  29.0  43.0  63.0  348.0
3.0              1506.0  59.061753  43.427729  7.0  33.0  47.0  70.0  377.0
4.0              2328.0  60.505584  44.988916  8.0  34.0  49.0  72.0  388.0
5.0             10546.0  55.462450  41.708457  4.0  31.0  45.0  65.0  396.0

             sentence_count
                      count      mean       std  min  25%  50%  75%   max
rating_value
1.0                  2705.0  3.797043  2.396340  1.0  2.0  3.0  5.0  27.0
2.0                  1471.0  3.766825  2.348979  1.0  2.0  3.0  5.0  21.0
3.0                  1506.0  4.017264  2.680996  1.0  2.0  3.0  5.0  24.0
4.0                  2328.0  4.330326  2.713269  1.0  3.0  4.0  5.0  25.0
5.0                 10546.0  4.404419  2.641970  1.0  3.0  4.0  5.0  29.0
```

The boxplots show that review length (in words and sentences) increases slightly with higher ratings, but the effect is modest and there is substantial overlap across all rating categories. Median word count rises from around 40–45 words for 1–2 star reviews to about 55–60 words for 4–5 star reviews, indicating that more satisfied customers tend to write somewhat longer reviews. However, the interquartile ranges overlap heavily, and all rating groups have many outliers extending above 150–200 words, so very long and very short reviews appear at every rating level. Median sentence count increases from roughly 2–3 sentences for low ratings to about 4–5 sentences for high ratings, again suggesting that higher ratings are associated with slightly more elaborated narratives.

In [18]:

```
# Vocabulary size vs review length

plt.figure(figsize=(7, 5))
sns.scatterplot(data=df_unique.sample(min(5000, len(df_unique)), random_stat
                x='word_count', y='unique_words', alpha=0.4, color='#8be9fd'
plt.title('Unique Words vs Word Count')
plt.xlabel('Word Count')
plt.ylabel('Unique Words')
plt.show()
```

```
# print correlation
corr_vocab_len = df_unique['word_count'].corr(df_unique['unique_words'])
print(f"\nCorrelation (Word_Count vs Unique_Words): {corr_vocab_len:.3f}")
```

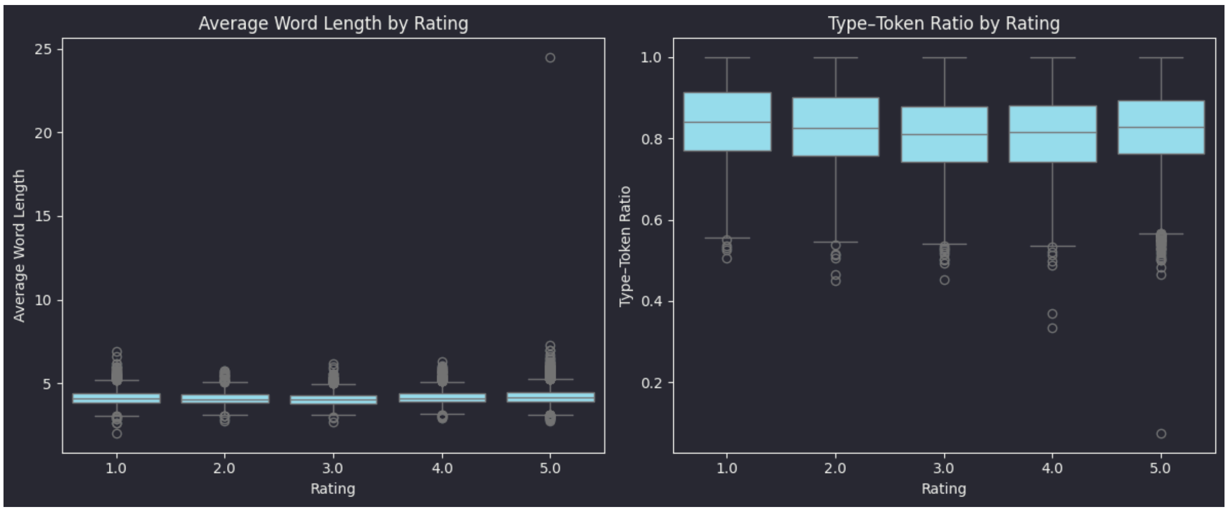



```
Correlation (Word_Count vs Unique_Words): 0.984
```

This plot shows a strong, almost linear relationship between review length and lexical diversity: as reviews get longer, they introduce more unique words, but with gradually decreasing marginal gains. For short reviews (up to 50 words), the number of unique words rises almost one-to-one with word count, implying very little repetition and highly compact messages. Beyond 100–150 words, the curve starts to flatten slightly, meaning additional length comes with more repeated words, but even at 300+ words reviews still contain well over 150 unique tokens, indicating high vocabulary richness and authentic human writing in this corpus.

In [19]:
```
# Readability / style proxies

# Type–token ratio
df_unique['type_token_ratio'] = df_unique['unique_words'] / df_unique['word_

plt.style.use(matplotx.styles.dracula)
plt.figure(figsize=(12, 5))

plt.subplot(1, 2, 1)
sns.boxplot(data=df_unique, x='rating_value', y='avg_word_length', color='#8
```

```python
plt.title('Average Word Length by Rating')
plt.xlabel('Rating')
plt.ylabel('Average Word Length')

plt.subplot(1, 2, 2)
sns.boxplot(data=df_unique, x='rating_value', y='type_token_ratio', color='#
plt.title('Type–Token Ratio by Rating')
plt.xlabel('Rating')
plt.ylabel('Type–Token Ratio')

plt.tight_layout()
plt.show()

print("\nReadability/style by rating (group means):")
print(df_unique.groupby('rating_value')[['avg_word_length', 'type_token_rati
```



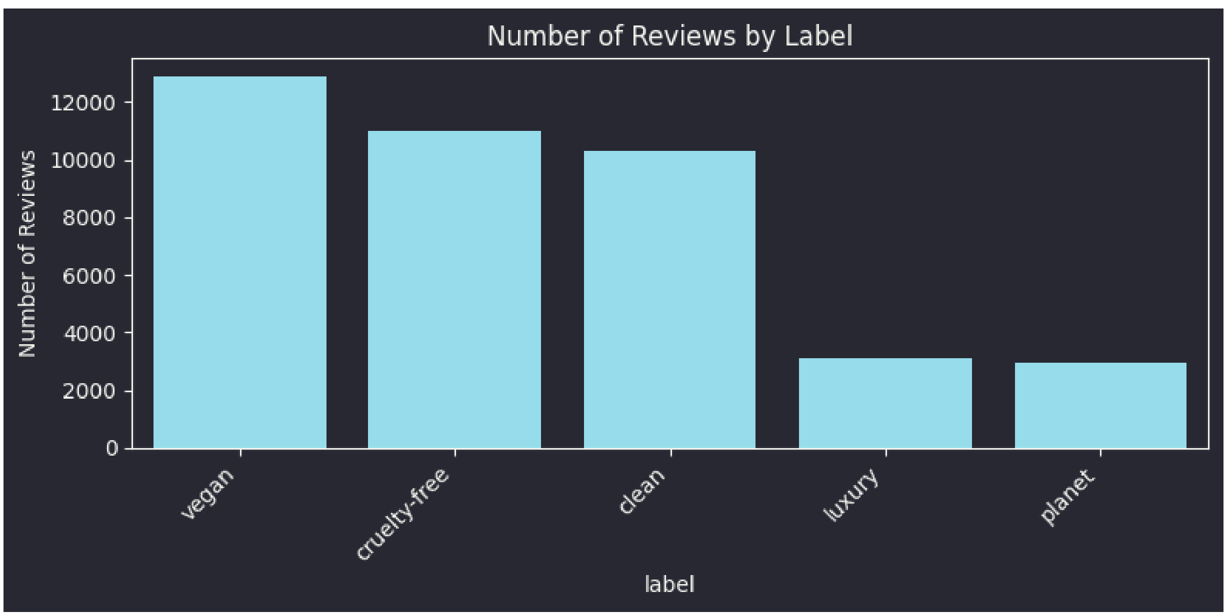

```
Readability/style by rating (group means):
              avg_word_length  type_token_ratio
rating_value
1.0                  4.145734          0.837263
2.0                  4.098953          0.823956
3.0                  4.056437          0.807156
4.0                  4.161627          0.811335
5.0                  4.224821          0.827473
```

These results suggest that writing style is broadly similar across ratings, with only subtle differences in complexity and lexical variety. Mean average word length ranges narrowly from about 4.06 to 4.22 characters, with 3-star reviews using slightly shorter words and 5-star reviews slightly longer ones. Type-token ratio (TTR) values are high overall (around 0.80–0.84), indicating rich vocabulary and low repetition in reviews at every rating level. 1-star and 5-star reviews show slightly higher TTR than mid-range ratings, which suggests that very satisfied or very dissatisfied customers tend to use a bit more varied language when describing their experiences, while neutral/mixed reviews are marginally more repetitive.

Overall, EDA shows that average sentiment polarity increases sharply between 3 and 4 stars, while the difference between 1–2–3 is smaller compared to the 3–4 and 4–5 jumps. This suggests that the main semantic boundary in the data lies between 3 and 4 stars. In the light of this findings, using 4–5 as positive and 1–3 as negative categories matches the binary label, that we applied above, with the underlying sentiment structure of the corpus.

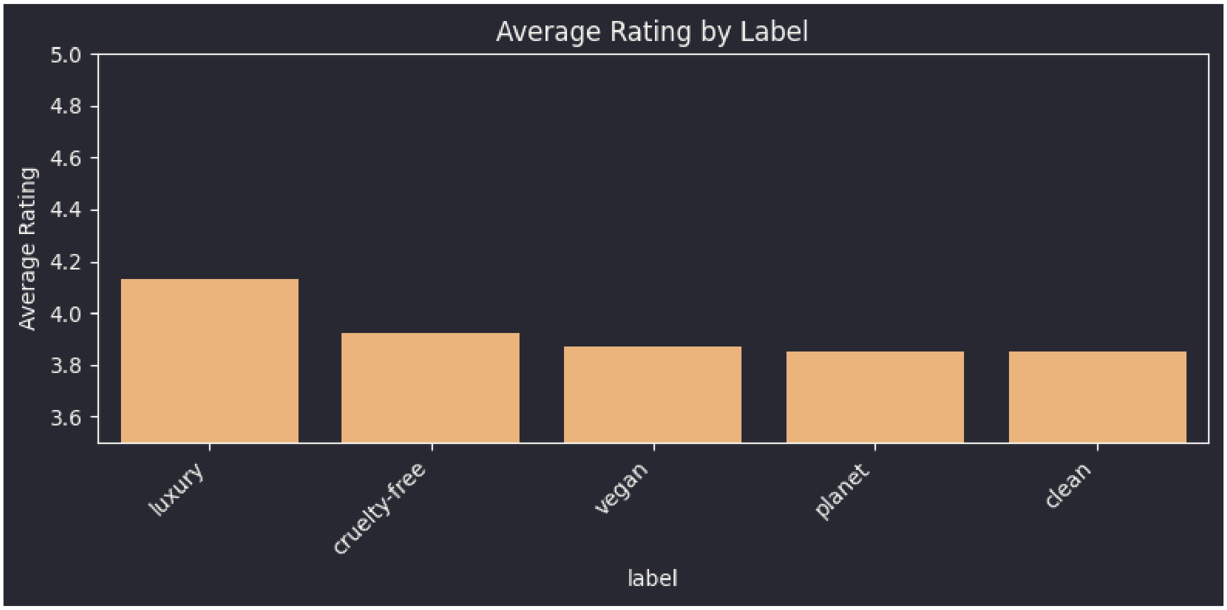
Other variables statistics

In [20]:
```
# Check labels
# Basic distribution of labels
label_counts = df['label'].value_counts(normalize=False)
label_prop   = df['label'].value_counts(normalize=True)

# Average rating and price by label
label_stats = df.groupby('label').agg(
    n_reviews      = ('review_id', 'count'),
    n_products     = ('name', 'nunique'),
    avg_rating     = ('rating_value', 'mean'),
    avg_agg_rating = ('aggregate_rating', 'mean'),
    avg_price      = ('price', 'mean')
).sort_values('n_reviews', ascending=False)

plt.figure(figsize=(8, 4))
label_counts = df['label'].value_counts().sort_values(ascending=False)

sns.barplot(x=label_counts.index, y=label_counts.values, color='#8be9fd')
plt.xticks(rotation=45, ha='right')
plt.ylabel('Number of Reviews')
plt.title('Number of Reviews by Label')
plt.tight_layout()
plt.show()
```



In [21]:
```
plt.figure(figsize=(8, 4))
label_rating = df.groupby('label')['rating_value'].mean().sort_values(ascend
sns.barplot(x=label_rating.index, y=label_rating.values, color='#ffb86c')
plt.xticks(rotation=45, ha='right')
```

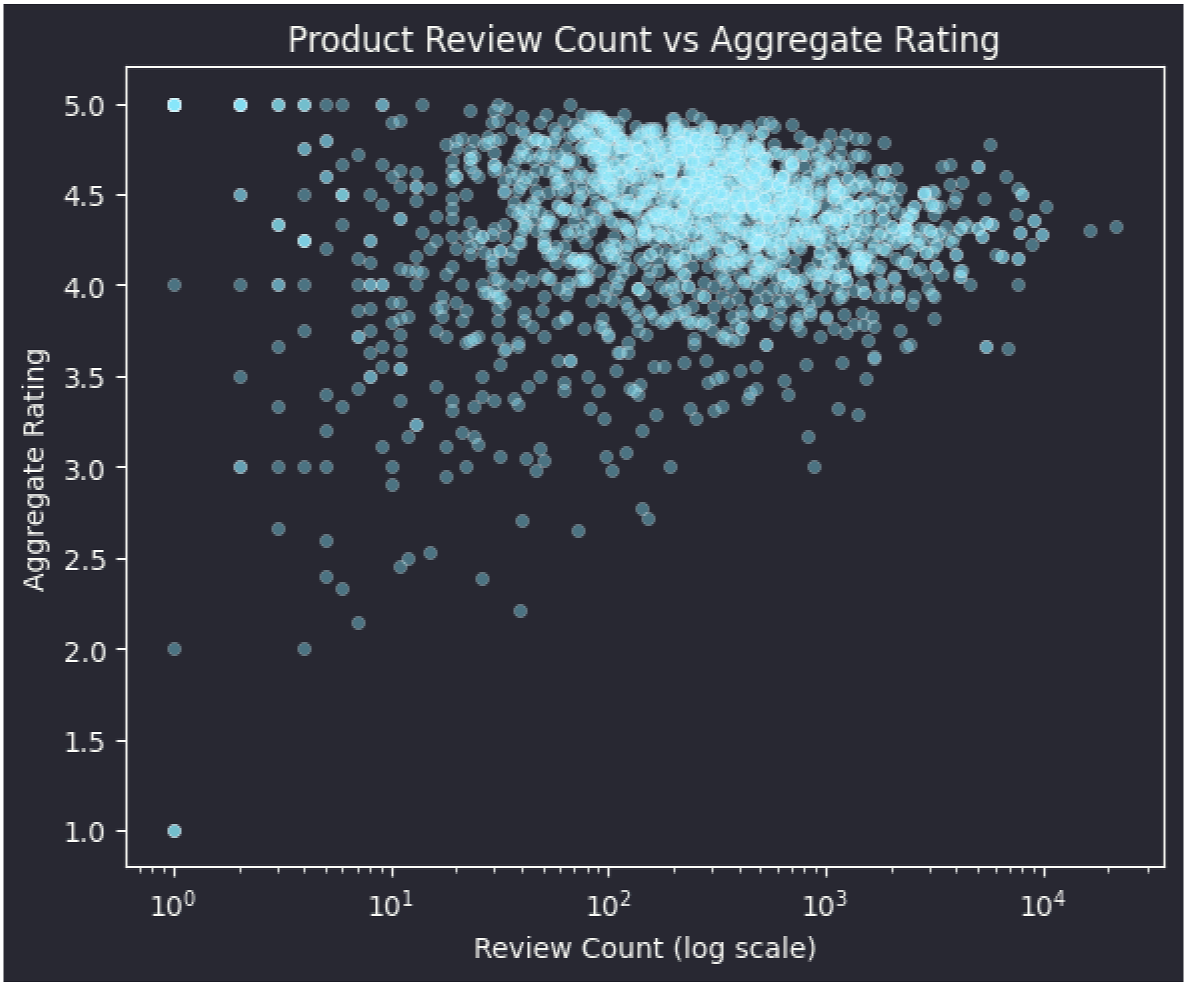
```
plt.ylabel('Average Rating')
plt.ylim(3.5, 5.0)
plt.title('Average Rating by Label')
plt.tight_layout()
plt.show()
```



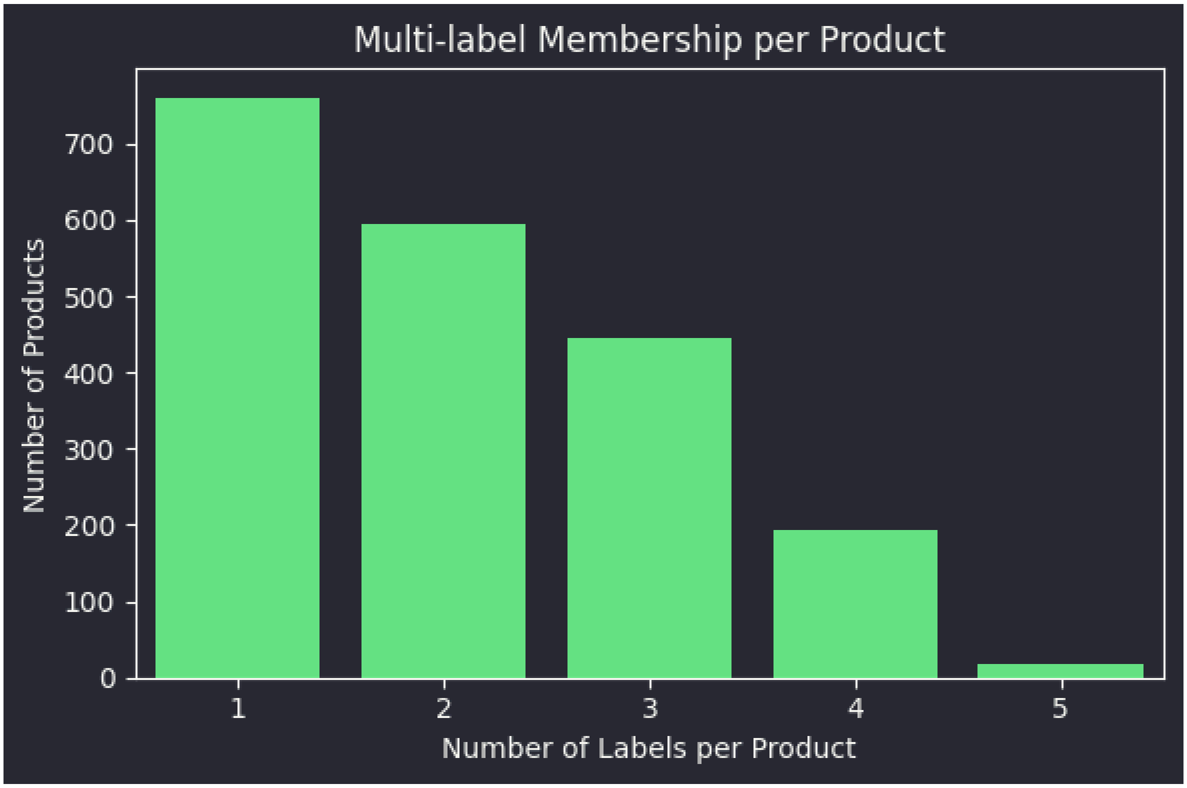
Vegan, cruelty-free, and clean products account for the large part of reviews, each with around 10k–13k observations, while luxury and planet labels are much smaller segments. This suggests that the dataset is primarily capturing mainstream "ethical/clean beauty" positioning, and inferences about luxury or planet products should be made cautiously due to lower sample size. Regarding the rating, all labels have fairly similar average ratings in the high-3s to low-4s range, indicating that customers are generally satisfied regardless of marketing label. Luxury products show a noticeably higher mean rating (around 4.1–4.2) than the other labels (around 3.85–3.9), which may reflect higher perceived performance, stronger brand expectations, or selection effects (fewer but more premium, well-reviewed items).

In [22]:
```
# Check products
product_stats = df.groupby(['name', 'brand', 'category']).agg(
    n_reviews    = ('review_id', 'nunique'),
    n_labels     = ('label', 'nunique'),
    review_count = ('review_count', 'max'),
    agg_rating   = ('aggregate_rating', 'max'),
    price        = ('price', 'max')
).reset_index()

plt.figure(figsize=(6, 5))
sns.scatterplot(
    data=product_stats,
    x='review_count', y='agg_rating',
    alpha=0.4, s=20
)
plt.xscale('log')
plt.xlabel('Review Count (log scale)')
```

```
plt.ylabel('Aggregate Rating')
plt.title('Product Review Count vs Aggregate Rating')
plt.tight_layout()
plt.show()
```

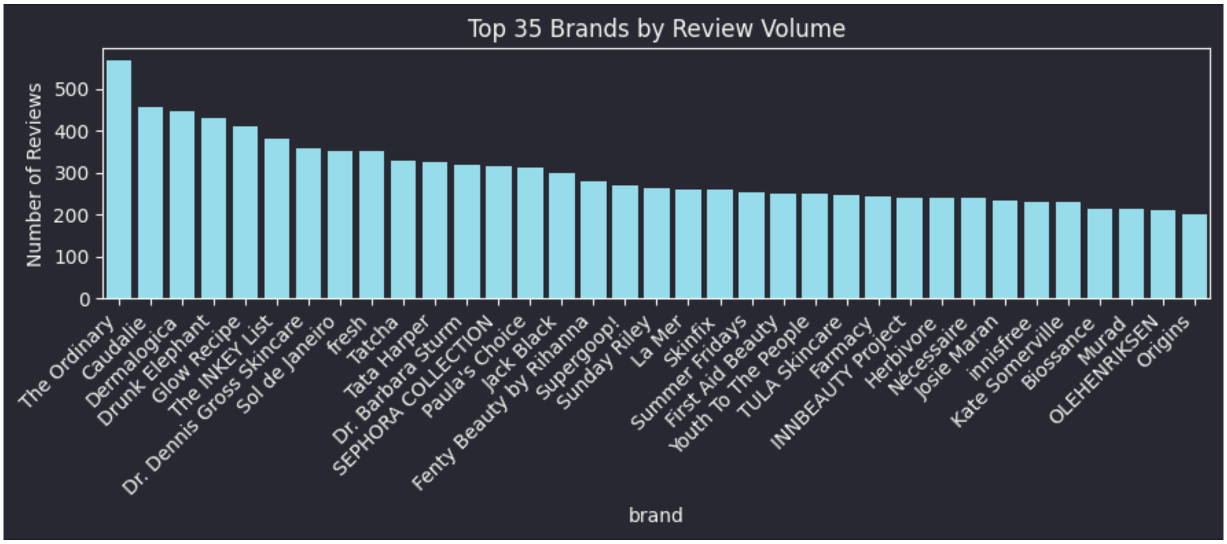


In [23]:
```
plt.figure(figsize=(6, 4))
sns.countplot(x='n_labels', data=product_stats, color='#50fa7b')
plt.xlabel('Number of Labels per Product')
plt.ylabel('Number of Products')
plt.title('Multi-label Membership per Product')
plt.tight_layout()
plt.show()
```

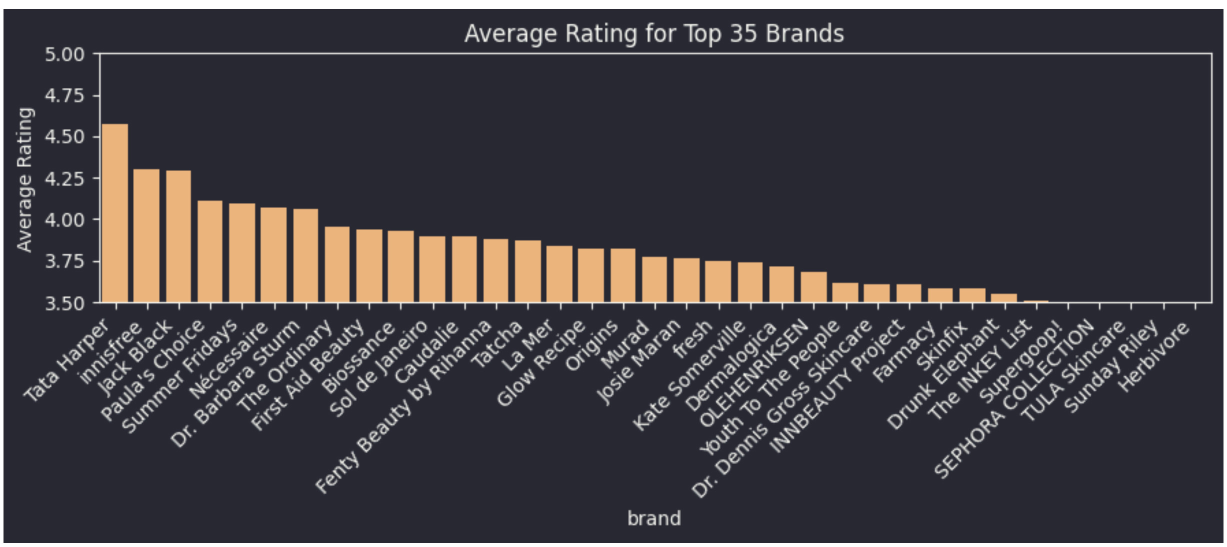


As we can see, most products carry only 1–3 labels, with the count dropping sharply for 4 and 5 labels. This means multi-label marketing (like “clean” + “vegan” + “cruelty-free”) is common but not a rule. Only a small minority of products are tagged with the full set of five labels. Regarding the "Product Review Count vs Aggregate Rating" plot, the cloud of points sits mostly between 4.0 and 4.8 aggregate rating regardless of review count, indicating that heavily reviewed products are not systematically higher- or lower-rated. We can notice thta even products with many reviews maintain relatively high averages.

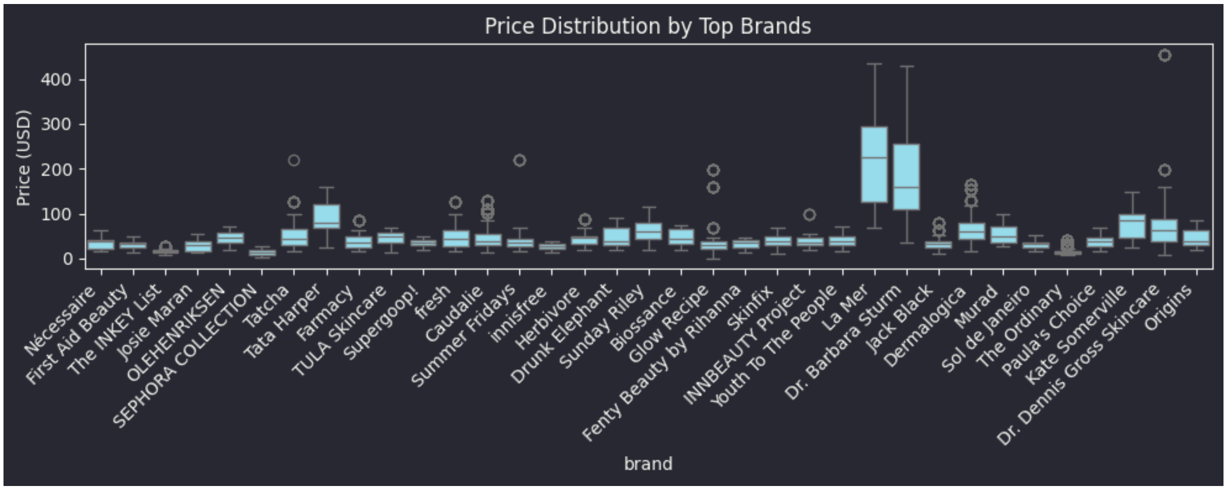
In [24]:
```
# Check brands
brand_stats = df.groupby('brand').agg(
    n_reviews   = ('review_id', 'nunique'),
    n_products = ('name', 'nunique'),
    avg_price   = ('price', 'mean'),
    avg_rating = ('rating_value', 'mean')
).reset_index()

top_brands = brand_stats.sort_values('n_reviews', ascending=False).head(35)

plt.figure(figsize=(9, 4))
sns.barplot(
    data=top_brands,
    x='brand', y='n_reviews', color='#8be9fd'
)
plt.xticks(rotation=45, ha='right')
plt.ylabel('Number of Reviews')
plt.title('Top 35 Brands by Review Volume')
plt.tight_layout()
plt.show()
```



In [25]:
```
plt.figure(figsize=(9, 4))
sns.barplot(
    data=top_brands.sort_values('avg_rating', ascending=False),
    x='brand', y='avg_rating', color='#ffb86c'
)
plt.xticks(rotation=45, ha='right')
plt.ylabel('Average Rating')
plt.ylim(3.5, 5.0)
plt.title('Average Rating for Top 35 Brands')
plt.tight_layout()
plt.show()
```



In [26]:
```
plt.figure(figsize=(10, 4))
sns.boxplot(
    data=df[df['brand'].isin(top_brands['brand'])],
    x='brand', y='price'
)
plt.xticks(rotation=45, ha='right')
plt.ylabel('Price (USD)')
plt.title('Price Distribution by Top Brands')
plt.tight_layout()
plt.show()
```

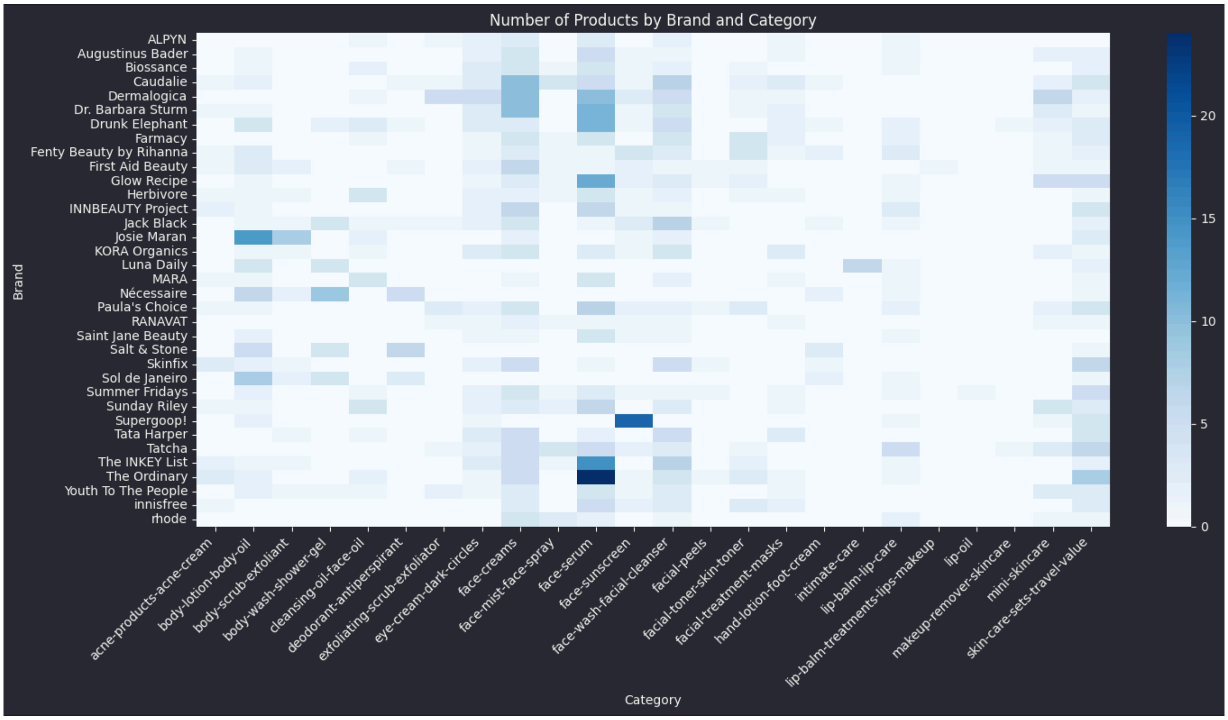


As we can see from the review volume by brand plot, review counts are heavily skewed: a few mass brands (notably The Ordinary, Caudalie, Dermalogica, Drunk Elephant, Glow Recipe) account for far more reviews than others, indicating they dominate visibility and customer engagement on Sephora. However, we can notice that other products on average have 200-400 reviews, which is not a bad indicator. Regarding the average rating for top brands, the top 35 brands fall in a narrow band between roughly 3.6 and 4.6, so customers are generally satisfied regardless of brand. Next, taking into consideration price distributioin, the boxplot shows large price dispersion across brands: Dr. Barbara Sturm, Tata Harper and La Mer sit clearly in the luxury tier with medians well above 150–200 USD and long upper tails, while others (like The Ordinary, Paula's Choice, The INKEY List) cluster below 30 USD. Several brands have wide within-brand ranges, indicating they span entry to premium price points, whereas a few budget brands have tight, low-price boxes, reflecting consistent affordable positioning.

Overall, there is no simple monotonic relationship between price, popularity, and rating: some premium brands are well rated but niche, some affordable brands are extremely popular with solid ratings, and all brands operate in a restricted high-rating band typical for retail platforms.

In [27]:
```python
# Check how the brands spreaded across different product categories. Take to
# Restrict to most frequent brands and categories
brand_counts = df['brand'].value_counts()
cat_counts   = df['category'].value_counts()
top_brands = brand_counts.head(35).index
top_cats   = cat_counts.head(25).index
df_bc = df[df['brand'].isin(top_brands) & df['category'].isin(top_cats)]

# Count products per (brand, category) at product level
prod_bc = (
    df_bc.groupby(['brand', 'category'])['name']
         .nunique()
         .reset_index(name='n_products')
)

# Pivot for heatmap
```

```python
pivot = prod_bc.pivot(index='brand', columns='category', values='n_products'

plt.figure(figsize=(15, 8))
sns.heatmap(pivot, annot=False, cmap='Blues')
plt.title('Number of Products by Brand and Category')
plt.xlabel('Category')
plt.ylabel('Brand')
plt.xticks(rotation=45, ha='right')
plt.tight_layout()
plt.show()
```



The heatmap shows how each brand's catalog is distributed across skincare categories, and it highlights which brands are specialists in a particular dimension. Darker cells indicate more products for a given (brand, category) combination, while white cells mean the brand has no products in that category. A few brands have strong vertical bands (dark cells concentrated in one or two categories), suggesting specialization. For example, some brands focus heavily on face serums, facial cleansers, or sunscreens rather than covering the whole routine. Other brands show multiple mid-tone cells across many categories, indicating a broader, "full-routine" positioning with cleansers, treatments, moisturizers, eye creams, and body care all represented. Several categories on the x-axis have relatively few dark patches overall, which points to niche segments (like intimate care, deodorant, or specific exfoliants), whereas core facial skincare categories (cleansers, serums, moisturizers, masks) attract contributions from many brands.

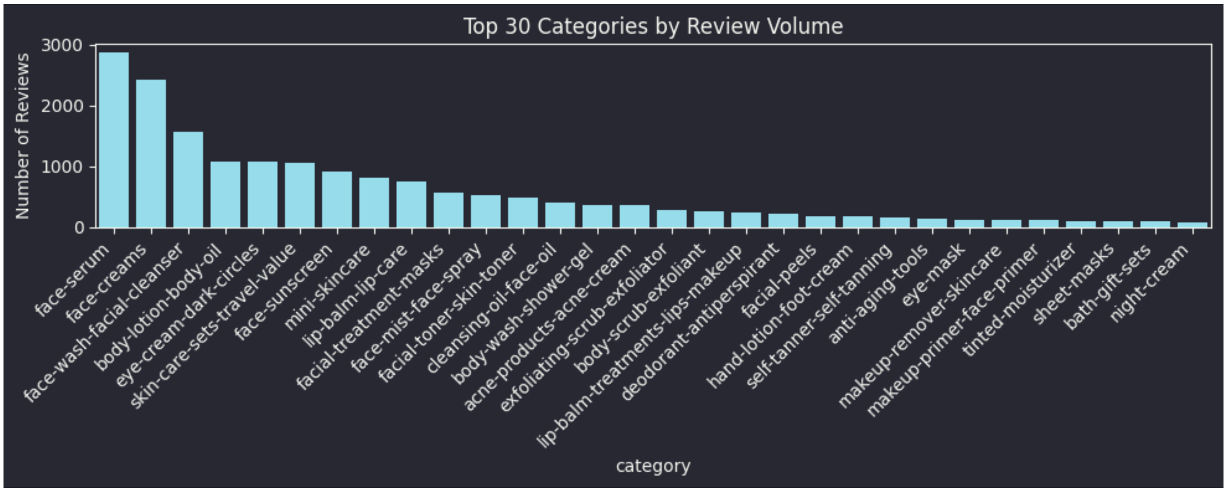
Taking specific products per particular category into consideration, The Ordinary and The INKEY List focus heavily on face serums and targeted treatments, with darker cells in serum/actives categories and relatively lighter presence in body care or lip care. Supergoop! is concentrated in face and body sunscreen categories, reflecting its clear

UV-protection positioning rather than a full skincare line. Sol de Janeiro shows density in body lotion, scrubs, and body-wash categories, confirming its emphasis on body care rather than facial skincare. Tata Harper, Dr. Barbara Sturm, and similar luxury brands appear mainly in high-end facial care (serums, creams, treatment masks), with few products in mass categories like basic cleansers or body wash.

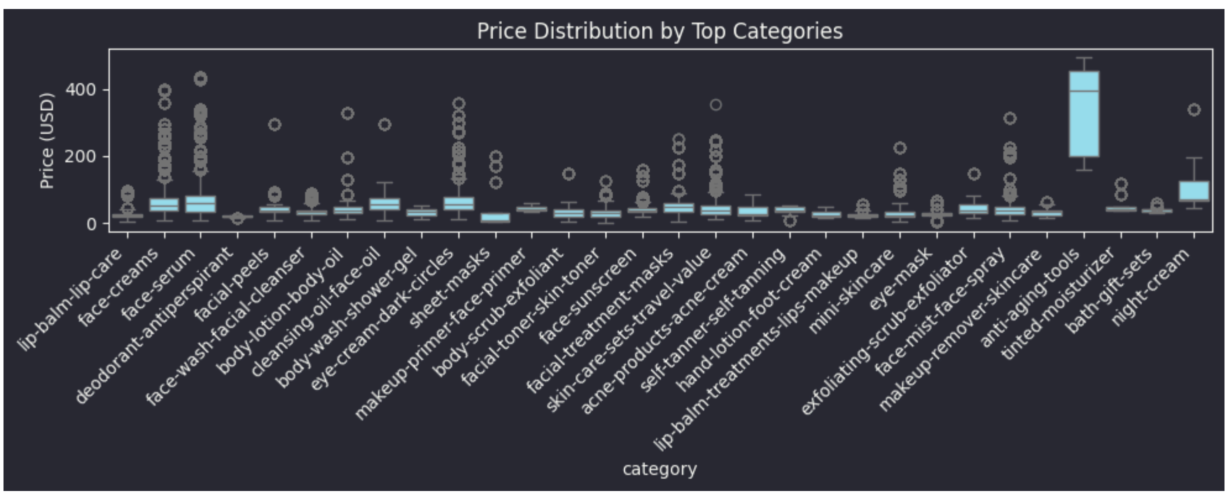
Caudalie, Fresh, Glow Recipe, and First Aid Beauty have mid-tone cells across several facial categories (cleansers, toners, serums, moisturizers, masks), indicating full-routine offerings rather than narrow specialization. Paula's Choice shows presence across exfoliants, serums, and moisturizers, with particular strength in exfoliating and treatment categories, matching its reputation for actives-driven skincare.

KORA Organics, Summer Fridays, Herbivore appear with a handful of products in specific categories like facial oils, masks, or eye creams, suggesting small but focused assortments. Categories such as intimate care, hand/foot creams, and lip treatments have only scattered darker cells, indicating that only a few brands actively compete in these spaces.

In [28]:
```python
# Check categories more precisely
cat_stats = df.groupby('category').agg(
    n_reviews  = ('review_id', 'nunique'),
    n_products = ('name', 'nunique'),
    avg_price  = ('price', 'mean'),
    avg_rating = ('rating_value', 'mean')
).reset_index()

cats_30 = cat_stats.sort_values('n_reviews', ascending=False).head(30)

plt.figure(figsize=(10, 4))
sns.barplot(
    data=cats_30,
    x='category', y='n_reviews', color='#8be9fd'
)
plt.xticks(rotation=45, ha='right')
plt.ylabel('Number of Reviews')
plt.title('Top 30 Categories by Review Volume')
plt.tight_layout()
plt.show()
```



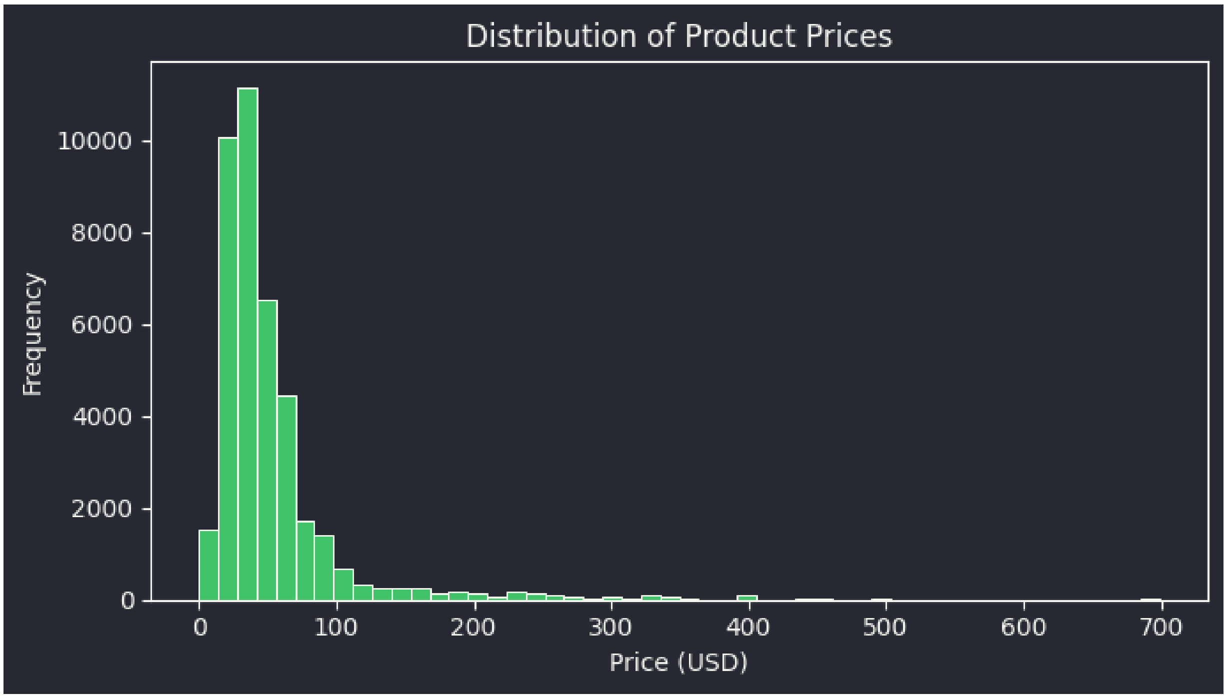
In [29]:
```python
plt.figure(figsize=(10, 4))
sns.boxplot(
    data=df[df['category'].isin(cats_30['category'])],
    x='category', y='price'
)
plt.xticks(rotation=45, ha='right')
plt.ylabel('Price (USD)')
plt.title('Price Distribution by Top Categories')
plt.tight_layout()
plt.show()
```



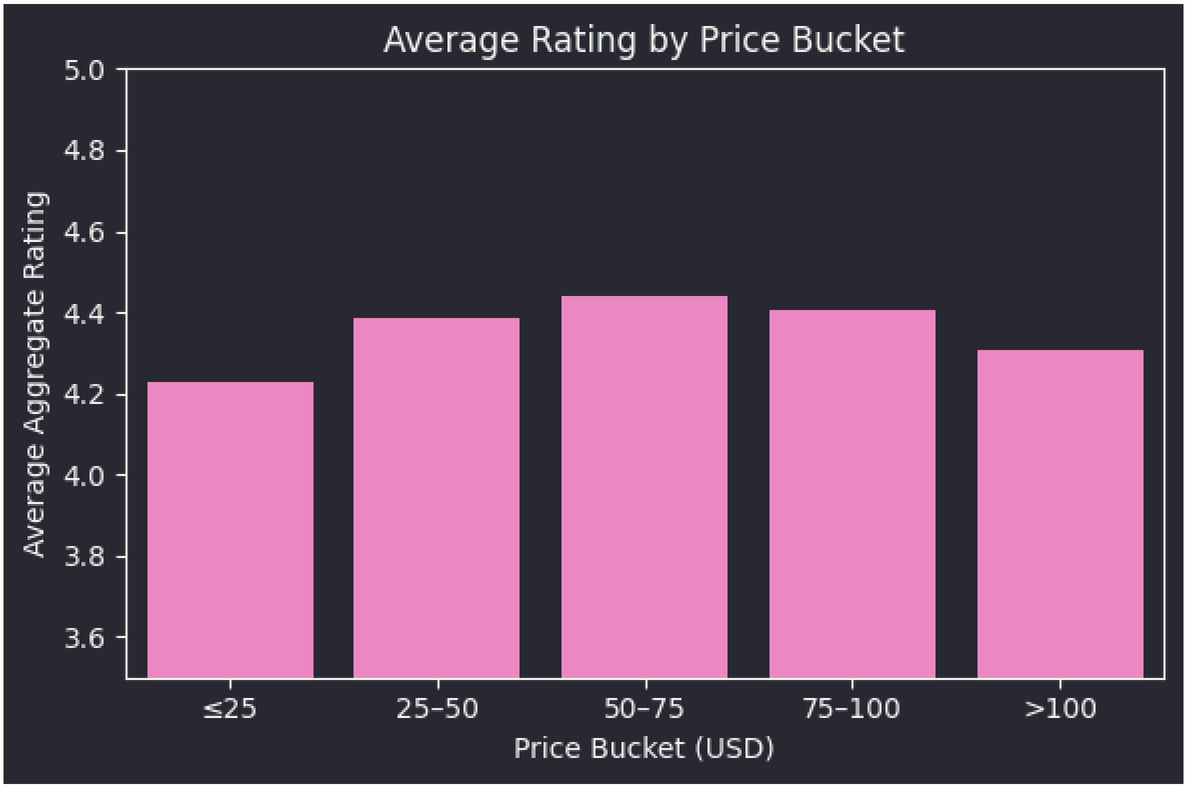
Across categories, prices and review volumes are highly uneven: a few core facial-care segments dominate both assortment and customer attention, while some categories command much higher price points than others. The price boxplot shows that typical prices vary strongly by category. Face serums, facial treatment masks, and anti-aging creams tend to sit at the higher end of the price spectrum, with many products above 100 USD and some extreme luxury outliers above 300–400 USD. Everyday items like face cleansers, body wash, deodorant, and lip balm cluster at much lower medians, often under 40–50 USD, reflecting their commodity status and larger packaging sizes. Several categories show wide boxes and long whiskers, which indicates substantial internal segmentation—from entry-level options to very premium ones within the same functional type. For example: treatment sets, bath sets, night creams.

The review bar chart reveals that face serums and face creams are by far the most reviewed categories, followed by facial cleansers, body lotion, eye creams, and sunscreen. This pattern matches typical skincare routines: products applied directly to the face and used daily (serums, moisturizers, cleansers) generate the most customer engagement and feedback, while niche items receive far fewer reviews.

In [30]:
```
# Price and rating
plt.figure(figsize=(7, 4))
sns.histplot(df['price'], bins=50, color='#50fa7b')
plt.xlabel('Price (USD)')
plt.ylabel('Frequency')
plt.title('Distribution of Product Prices')
plt.tight_layout()
plt.show()
```



In [31]:
```
# Price buckets at product level
bins = [0, 25, 50, 75, 100, df['price'].max()]
labels = ['≤25', '25–50', '50–75', '75–100', '>100']
product_stats['price_bucket'] = pd.cut(product_stats['price'], bins=bins, la
price_bucket_stats = product_stats.groupby('price_bucket')['agg_rating'].mea

plt.figure(figsize=(6, 4))
sns.barplot(data=price_bucket_stats, x='price_bucket', y='agg_rating', color
plt.ylabel('Average Aggregate Rating')
plt.xlabel('Price Bucket (USD)')
plt.ylim(3.5, 5.0)
plt.title('Average Rating by Price Bucket')
plt.tight_layout()
plt.show()
```



From the distribution of product prices histogram we can see that data is strongly right-skewed: most products are priced between roughly 20 and 80 USD, with a sharp peak in this range and a long tail extending towards very high prices (above 300–400 USD and up to around 700 USD). This indicates that the Sephora skincare assortment is dominated by mid-priced products, while ultra-premium items exist but are relatively rare. These outliers represent luxury or treatment products rather than the big part of the catalog. Regarding the average rating per price range, the average aggregate rating stays between about 4.2 and 4.45 across all buckets. Ratings rise slightly from the lowest bucket to the 50–75 USD range and then level off or dip marginally, suggesting that paying more does not guarantee dramatically higher satisfaction, but very cheap products may perform a bit worse on average.

Word cloud analysis

In [32]:
```
fig, axes = plt.subplots(1, 2, figsize=(20, 8))

positive_text = ' '.join(df_unique[df_unique['rating_binary'] == 1]['process
wordcloud_pos = WordCloud(width=800, height=400, background_color='#282a36',
                          colormap='Greens').generate(positive_text)
axes[0].imshow(wordcloud_pos, interpolation='bilinear')
axes[0].axis('off')
axes[0].set_title('Positive Reviews Word Cloud', fontsize=16, fontweight='bo

negative_text = ' '.join(df_unique[df_unique['rating_binary'] == 0]['process
wordcloud_neg = WordCloud(width=800, height=400, background_color='#282a36',
                          colormap='Reds').generate(negative_text)
axes[1].imshow(wordcloud_neg, interpolation='bilinear')
```

```
axes[1].axis('off')
axes[1].set_title('Negative Reviews Word Cloud', fontsize=16, fontweight='bo

plt.tight_layout()
plt.show()
```

From the word cloud plot, positive reviews side, we can see that the most prominent words are "love", "great", "amazing", "product", "moisturizer", "serum", "hydrating", and "skin", which emphasizes strong affection and perceived effectiveness. Frequent co-occurring terms like "dry skin", "sensitive skin", "feel", "glow", "hydrating", "scent" suggest that satisfied customers focus on comfort, hydration, texture, and how the product makes their skin feel and look, especially for dry or sensitive skin types.

On the other side, negative review cloud part, we can notice that words "product", "skin", "smell/scent", "used", "really", "dry", "sensitive", "packaging" are dominant. Compared with positive reviews, there is more emphasis on smell, packaging, and irritation: terms like "smell", "scent", "burn", "breakout", "dry skin", "sensitive skin", "bottle" point to complaints about fragrance, adverse reactions, dryness, and practical issues with the container or dispenser.

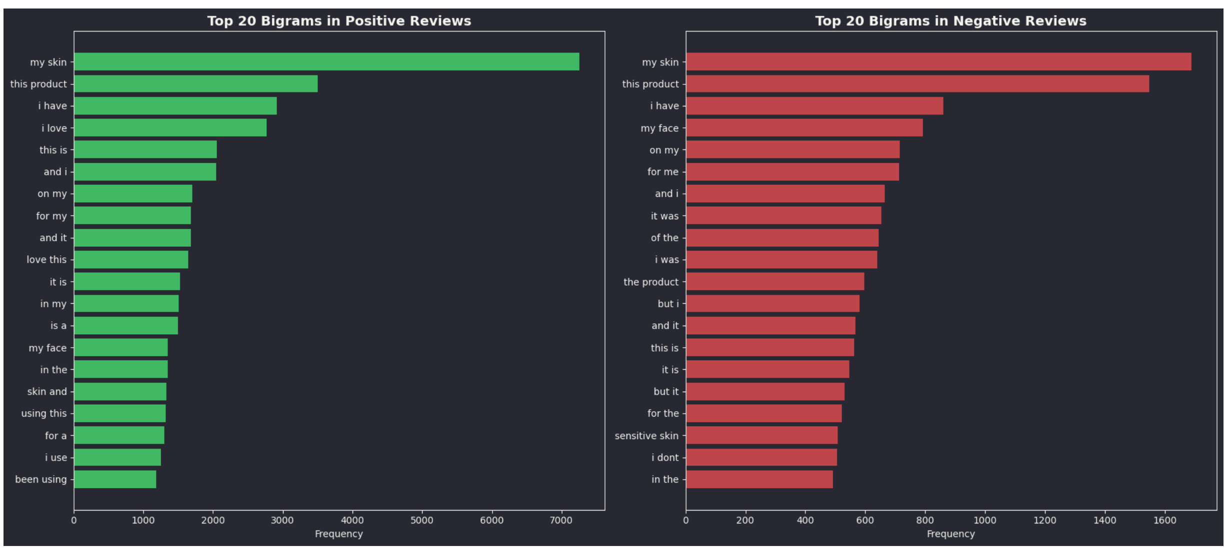
Overall, both groups talk heavily about product and skin, but the emotional polarity and focus differ: positive reviews center on love, glow, hydration, and comfort, while negative reviews highlight smell, irritation, dryness, and packaging problems.

N-grams

In [33]:
```
def extract_ngrams(text_series, n=2, top_n=20):
    """Extract top n-grams from text series"""
    all_ngrams = []
    for text in text_series:
        if isinstance(text, str) and text:
            tokens = word_tokenize(text.lower())
            ngrams_list = list(ngrams(tokens, n))
            all_ngrams.extend(ngrams_list)

    ngram_freq = Counter(all_ngrams)
    return ngram_freq.most_common(top_n)

bigrams_positive = extract_ngrams(df_unique[df_unique['rating_binary'] == 1]
bigrams_negative = extract_ngrams(df_unique[df_unique['rating_binary'] == 0]
```

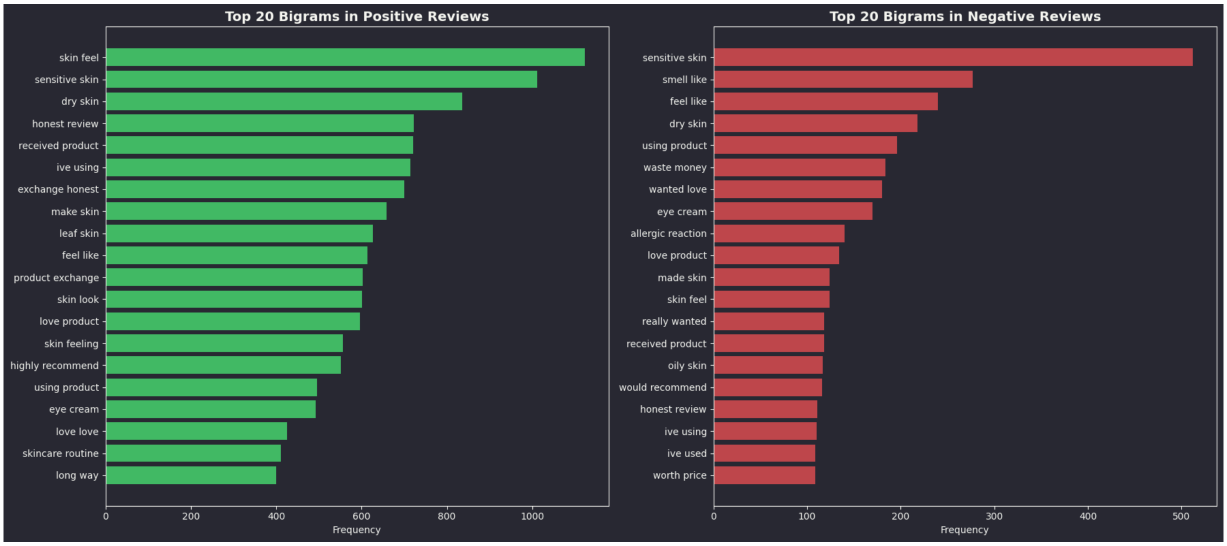
```
bigrams_positive_cl = extract_ngrams(df_unique[df_unique['rating_binary'] ==
bigrams_negative_cl = extract_ngrams(df_unique[df_unique['rating_binary'] ==

trigrams_positive = extract_ngrams(df_unique[df_unique['rating_binary'] == 1
trigrams_negative = extract_ngrams(df_unique[df_unique['rating_binary'] == 0

fivegrams_positive = extract_ngrams(df_unique[df_unique['rating_binary'] ==
fivegrams_negative = extract_ngrams(df_unique[df_unique['rating_binary'] ==
```

In [34]:
```
fig, axes = plt.subplots(1, 2, figsize=(18, 8))

bigrams_pos_text = [' '.join(ng) for ng, _ in bigrams_positive_cl]
bigrams_pos_freq = [freq for _, freq in bigrams_positive_cl]
axes[0].barh(bigrams_pos_text[::-1], bigrams_pos_freq[::-1], color='#50fa7b'
axes[0].set_xlabel('Frequency')
axes[0].set_title('Top 20 Bigrams in Positive Reviews', fontsize=14, fontwei

bigrams_neg_text = [' '.join(ng) for ng, _ in bigrams_negative_cl]
bigrams_neg_freq = [freq for _, freq in bigrams_negative_cl]
axes[1].barh(bigrams_neg_text[::-1], bigrams_neg_freq[::-1], color='#ff5555'
axes[1].set_xlabel('Frequency')
axes[1].set_title('Top 20 Bigrams in Negative Reviews', fontsize=14, fontwei

plt.tight_layout()
plt.show()
```



In [35]:
```
fig, axes = plt.subplots(1, 2, figsize=(18, 8))

bigrams_pos_text = [' '.join(ng) for ng, _ in bigrams_positive]
bigrams_pos_freq = [freq for _, freq in bigrams_positive]
axes[0].barh(bigrams_pos_text[::-1], bigrams_pos_freq[::-1], color='#50fa7b'
axes[0].set_xlabel('Frequency')
axes[0].set_title('Top 20 Bigrams in Positive Reviews', fontsize=14, fontwei

bigrams_neg_text = [' '.join(ng) for ng, _ in bigrams_negative]
bigrams_neg_freq = [freq for _, freq in bigrams_negative]
axes[1].barh(bigrams_neg_text[::-1], bigrams_neg_freq[::-1], color='#ff5555'
axes[1].set_xlabel('Frequency')
```

```
axes[1].set_title('Top 20 Bigrams in Negative Reviews', fontsize=14, fontwei

plt.tight_layout()
plt.show()
```

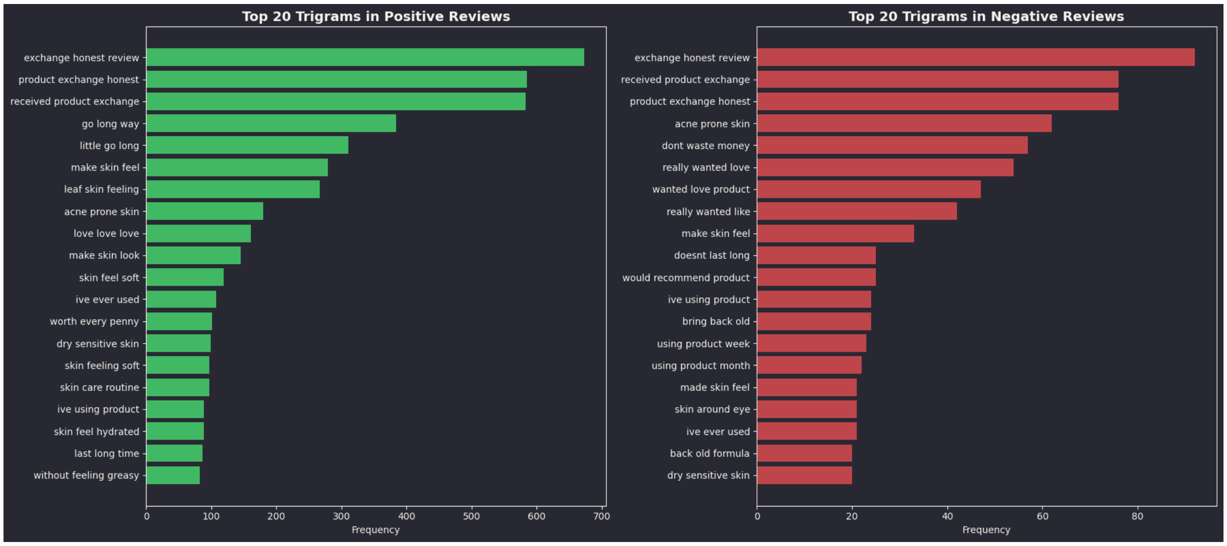


First, we computed bigrams on lightly cleaned text, which showed that both positive and negative reviews are written from a strongly personal perspective (bigrams like "my skin", "this product", "i have"), but many of the top bigrams consisted mostly of function words and carried limited semantic content.

Then, using the processed_review datafame, lemmatized text with stopwords removed, we obtained more meaningful bigrams that highlight product attributes and outcomes, such as "skin feel", "dry skin", "sensitive skin", "smell like", "waste money", and "allergic reaction".

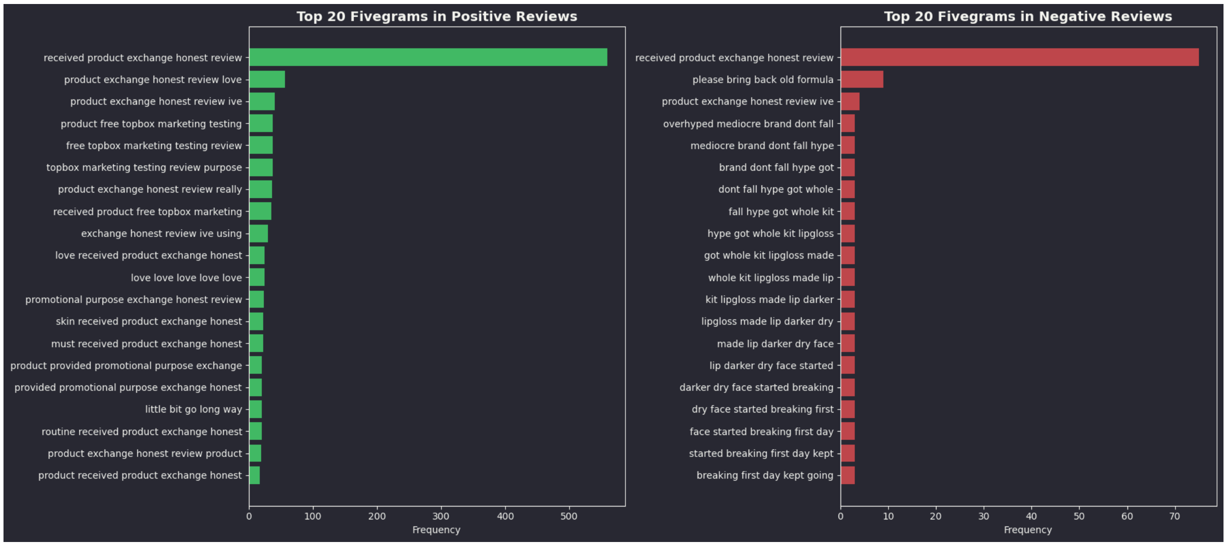
Comparing positive vs negative bigrams on the processed text reveals that hydration, pleasant feel, and suitability for sensitive/dry skin are key drivers of satisfaction, whereas scent, irritation on sensitive or oily skin, and perceived value for money are central themes in negative reviews.

In [36]:
```
fig, axes = plt.subplots(1, 2, figsize=(18, 8))

trigrams_pos_text = [' '.join(ng) for ng, _ in trigrams_positive]
trigrams_pos_freq = [freq for _, freq in trigrams_positive]
axes[0].barh(trigrams_pos_text[::-1], trigrams_pos_freq[::-1], color='#50fa7
axes[0].set_xlabel('Frequency')
axes[0].set_title('Top 20 Trigrams in Positive Reviews', fontsize=14, fontwe

trigrams_neg_text = [' '.join(ng) for ng, _ in trigrams_negative]
trigrams_neg_freq = [freq for _, freq in trigrams_negative]
axes[1].barh(trigrams_neg_text[::-1], trigrams_neg_freq[::-1], color='#ff555
axes[1].set_xlabel('Frequency')
axes[1].set_title('Top 20 Trigrams in Negative Reviews', fontsize=14, fontwe

plt.tight_layout()
plt.show()
```



Trigram analysis on processed reviews shows that positive reviews frequently mention long-lasting products ("go long way", "last long time"), pleasant non-greasy skin feel ("skin feel soft", "without feeling greasy"), and good performance on dry or sensitive skin ("dry sensitive skin"), alongside explicit value statements ("worth every penny"). In contrast, negative reviews revolve around disappointment and value concerns ("dont waste money", "really wanted love [the product]", "doesnt last long", "make skin feel"), lack of results over weeks or months, and issues for sensitive skin or after formula changes ("back old formula").

In [37]:
```
fig, axes = plt.subplots(1, 2, figsize=(18, 8))

fivegrams_pos_text = [' '.join(ng) for ng, _ in fivegrams_positive]
fivegrams_pos_freq = [freq for _, freq in fivegrams_positive]
axes[0].barh(fivegrams_pos_text[::-1], fivegrams_pos_freq[::-1], color='#50f
axes[0].set_xlabel('Frequency')
axes[0].set_title('Top 20 Fivegrams in Positive Reviews', fontsize=14, fontw

fivegrams_neg_text = [' '.join(ng) for ng, _ in fivegrams_negative]
fivegrams_neg_freq = [freq for _, freq in fivegrams_negative]
axes[1].barh(fivegrams_neg_text[::-1], fivegrams_neg_freq[::-1], color='#ff5
axes[1].set_xlabel('Frequency')
axes[1].set_title('Top 20 Fivegrams in Negative Reviews', fontsize=14, fontw

plt.tight_layout()
plt.show()
```



As we can notice, almost all top 5-grams are variants of "received product exchange honest review", "product exchange honest review love", and phrases mentioning "free topbox marketing testing promotional purpose", which are standard disclosure sentences. This tells us that a substantial fraction of positive reviews come from incentivized or sample-based programs, but beyond that, 5-grams add little new information beyond what our trigrams already captured (like "go long way", "worth every penny").

The leading negative 5-gram is again the disclosure sentence ("received product exchange honest review"), showing that some negative reviews are also incentivized. The next set of 5-grams forms a coherent narrative about disappointment with a reformulated lip product: "please bring back old formula", "overhyped mediocre brand dont fall", "dont fall hype got whole kit", and a series of phrases about a lipgloss kit making lips darker and dry, skin breaking out from day one. These describe one or a few very specific product issues rather than broad patterns across the dataset.

This justifies focusing our substantive interpretation on bigrams and trigrams, where we captured clearer, recurring themes about hydration, sensitive skin, scent, irritation, and value for money across many products.

Text clustering

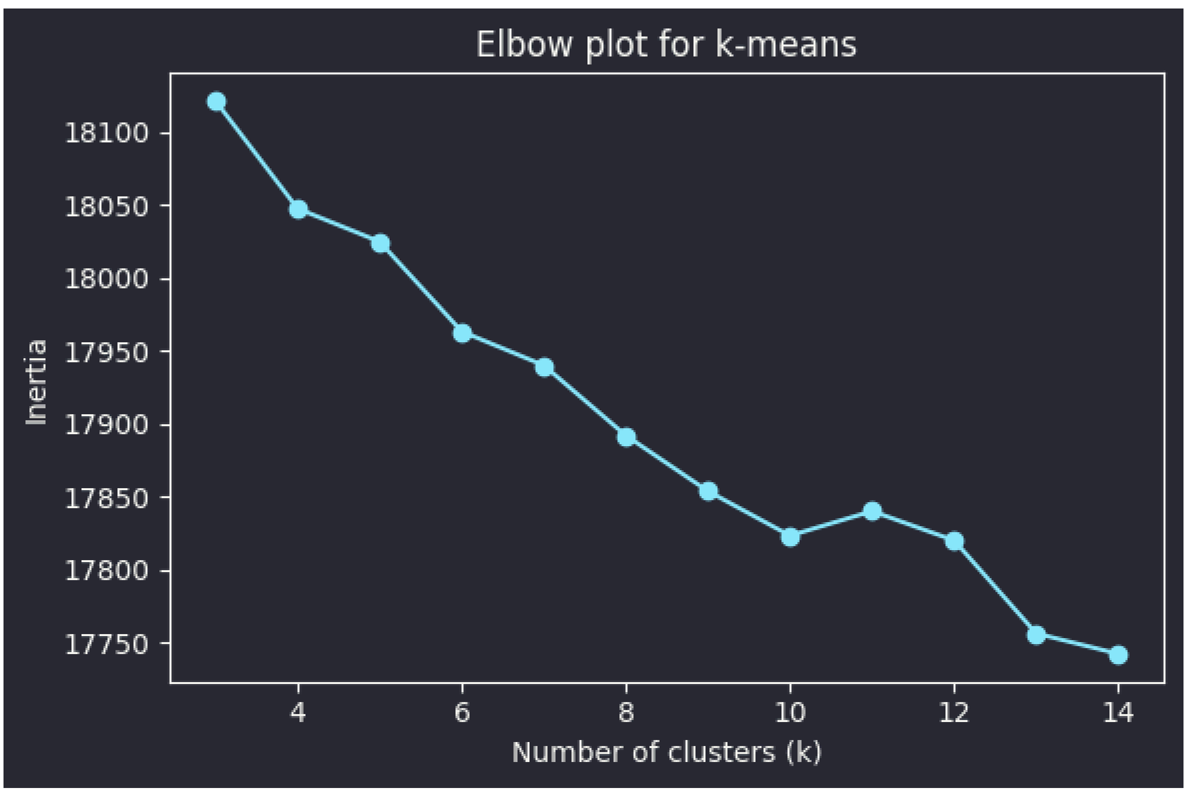
In [38]:
```
df_cluster = df_unique.copy()
texts = df_cluster['processed_review'].tolist()
```

In [39]:
```
tfidf = TfidfVectorizer(
    max_df=0.5,             # ignore extremely common terms
    min_df=10,              # ignore very rare terms
    ngram_range=(1, 2),     # unigrams + bigrams
    max_features=20000      # cap dimensionality
)
```

```python
X_tfidf = tfidf.fit_transform(texts)
feature_names = np.array(tfidf.get_feature_names_out())
print(f"TF-IDF matrix shape: {X_tfidf.shape}")
```

```
TF-IDF matrix shape: (18556, 8996)
```

In [40]:
```python
inertias = []
K_range = range(3, 15)

for k in K_range:
    km = MiniBatchKMeans(
        n_clusters=k,
        random_state=42,
        batch_size=2048,
        n_init=10
    )
    km.fit(X_tfidf)
    inertias.append(km.inertia_)

plt.figure(figsize=(6,4))
plt.plot(list(K_range), inertias, marker='o')
plt.xlabel("Number of clusters (k)")
plt.ylabel("Inertia")
plt.title("Elbow plot for k-means")
plt.tight_layout()
plt.show()
```



In [41]:
```python
k = 6  # set based on elbow plot
kmeans = MiniBatchKMeans(
    n_clusters=k,
    random_state=42,
    batch_size=2048,
    n_init=20
```

```
)
clusters = kmeans.fit_predict(X_tfidf)

df_cluster['cluster'] = clusters
```

In [42]:
```
def top_terms_per_cluster(model, feature_names, n_top=15):
    order_centroids = model.cluster_centers_.argsort(axis=1)[:, ::-1]
    cluster_terms = {}
    for i in range(model.n_clusters):
        terms = feature_names[order_centroids[i, :n_top]]
        cluster_terms[i] = terms
    return cluster_terms

cluster_keywords = top_terms_per_cluster(kmeans, feature_names, n_top=15)

for c, terms in cluster_keywords.items():
    print(f"\nCluster {c}:")
    print(", ".join(terms))
```

```
Cluster 0:
product, using, acne, used, use, face, ive, work, price, didnt, one, worth,
get, time, dont

Cluster 1:
smell, lip, like, product, feel, good, use, really, love, smell like, balm,
nice, dont, scent, using

Cluster 2:
sensitive, sensitive skin, cleanser, feeling, makeup, feel, great, face, lea
f, dry, use, moisturizer, doesnt, soft, sunscreen

Cluster 3:
honest, exchange, received product, honest review, exchange honest, receive
d, product exchange, review, product, feel, great, scent, nice, love, packag
ing

Cluster 4:
love, product, serum, feel, love product, routine, great, love love, must, u
se, scent, glow, make, amazing, way

Cluster 5:
eye, eye cream, cream, product, dark, work, circle, use, area, dark circle,
using, love, around, around eye, really
```

Now we can observe clusters in more details. Lets start with the first one.

Cluster 0 – Effectiveness, acne, and value for money, Top terms like "product, using, acne, used, use, face, ive, work" suggest reviews focused on whether the product works on the face, especially for acne-related concerns. The presence of "price, didnt, worth, get, time, dont" indicates many reviewers explicitly discuss value for money and disappointment when the product did not work over time, so this cluster is likely mixed or skewed negative on effectiveness + cost.

Cluster 1 – Lip products and scent. Keywords "smell, lip, like, balm, scent" clearly point to lip balms/glosses and fragrance. Mixed sentiment words ("good, really, love, nice" versus "dont") suggest that scent and feel on the lips are central evaluation criteria, with some users loving the fragrance/texture and others disliking it.

Cluster 2 – Sensitive skin, cleansers, and basic skincare. Phrases like "sensitive, sensitive skin, cleanser, makeup, face, moisturizer, sunscreen" show this cluster gathers core routine products (cleansers, moisturizers, sunscreen) aimed at sensitive or dry skin. Positive descriptors ("great, leaf, soft") plus negatives like "doesnt, dry" indicate a mix of reviews about how gentle or drying the products feel on sensitive skin.

Cluster 3 – Incentivized reviews and packaging. The dominant phrases "honest, exchange, received product, honest review, product exchange" are classic disclosure sentences for PR or sample products, marking this as the "incentivized review" cluster. Within those reviews, content words like "feel, great, scent, nice, love, packaging" show they often talk about pleasant feel, nice scent, and attractive packaging, so the tone is probably skewed positive but formally phrased.

Cluster 4 – Enthusiastic praise for serums and glow. Very positive sentiment words dominate: "love, love product, love love, great, amazing, must, glow" alongside "serum, routine, feel, scent, make, way". This looks like the "holy-grail serum / skincare routine" cluster, where users admire about how a product fits into their routine, provides glow, and is a must-have they genuinely love.

Cluster 5 – Eye creams and dark circles. Terms "eye, eye cream, cream, dark, circle, dark circle, area, around eye" clearly indicate eye-area treatments for dark circles. Words "work, using, love, really" show that reviews often focus on whether the cream actually improves dark circles and how it feels around the eyes, with both success and failure stories.

Overall, we can see that clustering reveals distinct thematic segments, such as acne and value, lip/scent products, sensitive-skin basics, incentivized reviews, glowing serum praise, and eye-cream evaluations. This confirms that the TF-IDF representation plus k-means is capturing meaningful structure in the review corpus.

In [43]:
```
cluster_summary = df_cluster.groupby('cluster').agg(
    n_reviews=('processed_review', 'count'),
    pos_share=('rating_binary', 'mean') # to check whether positive or negat
).reset_index()

cluster_summary['pos_share'] = cluster_summary['pos_share'].round(3)
cluster_summary
```

Out[43]:

	cluster	n_reviews	pos_share
0	0	6652	0.534
1	1	3140	0.591
2	2	3722	0.842
3	3	801	0.876
4	4	3158	0.944
5	5	1083	0.599

We can observe that clusters 2–4 capture clearly positive experiences (pos_share from 0.842 to 0.944), while clusters 0–1 and 5 contain more mixed or critical evaluations (pos_share between 0.534 and 0.599).

In [44]:
```
pd.crosstab(df_cluster['cluster'], df_cluster['label'])
```

Out[44]:

label	clean	cruelty-free	luxury	planet	vegan
cluster					
0	3336	1513	630	35	1138
1	1706	772	175	26	461
2	2009	859	313	38	503
3	343	319	102	1	36
4	1606	722	300	47	483
5	522	192	156	3	210

Additionally, we can see that highly positive clusters (2–4) are dominated by clean, cruelty-free, and often luxury products, especially for serums and sensitive-skin care, while more mixed clusters (0–1, 5) contain a higher fraction of mainstream clean/vegan offerings and targeted treatments where effectiveness and value are more contested.

In [45]:
```
pd.crosstab(df_cluster['cluster'], df_cluster['category'])
```

Out[45]:

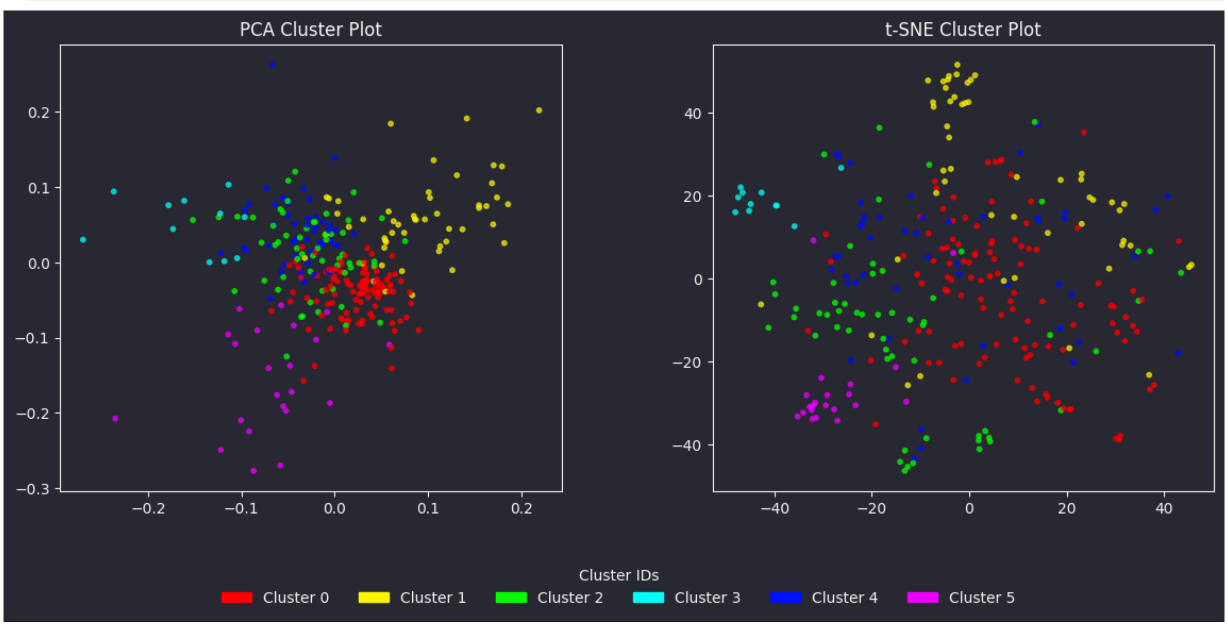
category	acne-products-acne-cream	anti-aging-tools	bath-gift-sets	bb-cc-cream-face-makeup	bb-cream-cc-cream	beauty-supplements-bath-body	blotting-paper-oil-control-skincare	blush
cluster								
0	260	92	24	3	6	6	5	12
1	24	9	20	2	2	1	0	17
2	24	5	15	1	1	0	1	2
3	12	1	1	0	0	0	0	0
4	50	34	35	3	1	3	4	18
5	0	9	0	1	0	0	0	1

From the product categories per cluster table we can also notice the same patterns. Acne-products-acne-cream is highest in cluster 0 (260 vs 24–50 in others), which matches our "acne/effectiveness/value" interpretation for cluster 0. Cluster 1 has by far the largest counts, especially lip-balm-lip-care (573) and lip-balm-treatments-lips-makeup (196), fitting the "lip + smell/feel" topic. Cluster 2 is very strong in face-wash-facial-cleanser (745), cleanser (67), face-sunscreen (342), and facial-toner-skin-toner (87), consistent with "sensitive skin / cleanser / sunscreen" reviews topic. Cluster 4 is strong in face-serum (679) and face-creams (433), and has good representation in sets/gifts, matching the "love love / serum / glow / routine" cluster. Cluster 5 is overwhelmingly dominated by eye-cream-dark-circles (670) and eye-mask (78), which fits the "eye cream / dark circles" topic.

In [46]:
```
pca = PCA(n_components=50, random_state=42)
X_pca = pca.fit_transform(X_tfidf.toarray())

tsne = TSNE(
    n_components=2,
    random_state=42,
    perplexity=40,
    learning_rate='auto',
    init='pca'
)
X_tsne = tsne.fit_transform(X_pca)

df_vis = pd.DataFrame({
    'tsne1': X_tsne[:,0],
    'tsne2': X_tsne[:,1],
    'cluster': clusters
})
```

In [47]:
```
def plot_tsne_pca(data, labels, seed=42):
    rng = np.random.RandomState(seed)
```

```python
    # Sample up to 3000 points for visualization
    n_samples = min(3000, data.shape[0])
    idx = rng.choice(data.shape[0], size=n_samples, replace=False)

    X = data[idx].toarray() if hasattr(data, "toarray") else np.asarray(data
    # PCA (2D)
    pca = PCA(n_components=2, random_state=seed).fit_transform(X)
    # PCA -> t-SNE
    X_50 = PCA(n_components=50, random_state=seed).fit_transform(X)
    tsne = TSNE(n_components=2, random_state=seed, perplexity=30).fit_transf

    # Random subset for clarity
    sub_idx = rng.choice(pca.shape[0], size=min(300, pca.shape[0]), replace=
    label_subset = np.array(labels)[idx][sub_idx]

    # Colors by cluster
    unique_labels = np.unique(labels)
    label_to_color = {l: cm.hsv(i / len(unique_labels)) for i, l in enumerat
    colors = [label_to_color[l] for l in label_subset]

    fig, ax = plt.subplots(1, 2, figsize=(14, 6))
    ax[0].scatter(pca[sub_idx, 0], pca[sub_idx, 1], c=colors, s=10, alpha=0.
    ax[0].set_title("PCA Cluster Plot")
    ax[1].scatter(tsne[sub_idx, 0], tsne[sub_idx, 1], c=colors, s=10, alpha=
    ax[1].set_title("t-SNE Cluster Plot")

    legend = [mpatches.Patch(color=c, label=f"Cluster {l}") for l, c in labe
    fig.legend(handles=legend, loc='lower center', ncol=len(unique_labels),
               title="Cluster IDs", bbox_to_anchor=(0.5, -0.02))

    plt.subplots_adjust(bottom=0.18, wspace=0.3)
    plt.show()

plot_tsne_pca(X_tfidf, clusters)
```



Both plots show that clusters are reasonably distinct but still overlap. PCA mainly captures global variance, so clusters 0–4 occupy overlapping clouds around the origin, with only mild separation along a diagonal direction. This suggests that, in the original TF-IDF space, clusters differ, but not by a few dominant linear directions. Topics share a lot of similar vocabulary, which compresses them into a tight region.

t-SNE emphasizes local neighborhood structure, and here it separates clusters much more clearly into colored "islands", especially clusters like 3 and 5 that become compact groups away from the center. The fact that most colors form coherent patches rather than being uniformly mixed indicates that k-means found semantically coherent clusters (reviews within a cluster tend to be similar to each other and dissimilar from others).

In [48]:
```
for c in range(k):
    print(f"\n=== Cluster {c} ===")
    print(", ".join(cluster_keywords[c]))
    subset = df_cluster[df_cluster['cluster'] == c].head(3)
    for idx, row in subset.iterrows():
        print(f"- ({'pos' if row['rating_binary']==1 else 'neg'}) {row['full
```

```
=== Cluster 0 ===
product, using, acne, used, use, face, ive, work, price, didnt, one, worth,
get, time, dont
- (pos) Great but.... This is a great product!  I have purchased this item i
n the glass pot (twice) and I was hooked.  I've also purchased now in the tu
be as it's a little more portable.  However, why was the little glass pot di
scontinued? Was this company s...
- (neg) stop changing things why must brands change things when its working?
the formula in the pot was perfect. It worked wonders and better than anythi
ng else out there. Now you have to change it to compete with the hundreds of
other lip products in this t...
- (neg) Not for me I’ve been using this product for two weeks now. It does m
oisturize, but it breaks me out. I notice a bunch of little pimples when I u
se it. Not for me, going to return....

=== Cluster 1 ===
smell, lip, like, product, feel, good, use, really, love, smell like, balm,
nice, dont, scent, using
- (neg) This lip balm is a miss for me It’s much thinner than I thought it w
ould be and the hydration doesn’t last very long. The flavor/scent also make
s me feel nauseous but that is just my opinion. I loveeeee Alpyn’s other pro
ducts but this just isn’t for ...
- (pos) Consistency is a great mix between a balm and an oil! My issue with
a lot of the new “lip oil” products is that its not an oil but a gloss and I
hate when something is too sticky and thick. This moisturizes my lips more t
han a traditional oil but jus...
- (pos) As someone who never writes reviews, I HAD TO for this product! It i
s absolutely amazing. Moisturizes my lips so well and stays on for hours. It
has become my go to lip product!...

=== Cluster 2 ===
sensitive, sensitive skin, cleanser, feeling, makeup, feel, great, face, lea
f, dry, use, moisturizer, doesnt, soft, sunscreen
- (pos) Good all purpose product A great product for my sensitive, milia-pro
ne skin....
- (pos) Top daily moisturizer I love this moisturizer 😭 i used to use just
a daily moisturizer sunscreen (Aveeno) and it irritates sometimes. This for
daily use is 🔥🔥🔥. It really does calm my skin and plump before my makeu
p...
- (pos) Good for dry skin Honestly a really good underrated moisturizer it m
ade my skin so glowy and not dry anymore...

=== Cluster 3 ===
honest, exchange, received product, honest review, exchange honest, receive
d, product exchange, review, product, feel, great, scent, nice, love, packag
ing
- (pos) use it daily [I received this product in exchange for my honest revi
ew] love te smell, it smells fresh and its not overpowering and lasts for ho
urs. The packaging is easy to use and the gel soap itself its that too harsh
and it lathers good....
- (pos) [I received this product in exchange for my honest review] This was
a nice body wash. It was moisturizing and gentle but left me feeling clean.
I think the package is sleek and easy to use. I would recommend this produc
t...
- (pos) Very nice I enjoy using this every time. I have switched to this was
h from my regular bar soap for my more sensitive areas. My skin is more mois
```

```
turized and soft, the scent is clean and light, and I experienced no irritat
ion from switching to this was...

=== Cluster 4 ===
love, product, serum, feel, love product, routine, great, love love, must, u
se, scent, glow, make, amazing, way
- (pos) Game changer So hydrating, so refreshing! Totally a game changer in
my routine! 10/10...
- (pos) I like how easy it makes my morning routine. It is also super hydrat
ing and smooth...
- (neg) I really wanted to love this. I normally use the Ole Henriksen Truth
Serum but wanted to splurge a little. I have oily skin and this made my face
look greasy and caused breakouts. Have to return....

=== Cluster 5 ===
eye, eye cream, cream, product, dark, work, circle, use, area, dark circle,
using, love, around, around eye, really
- (pos) 🌿 A Ritual for Awake Eyes & Radiant Presence 🌿 As a psychologist a
nd writer, my days are spent deep in thought, face to screen, heart to soul.
I rely on products that don't just promise results—they deliver calm, clarit
y, and care. This serum feels l...
- (pos) Light and gentle I misread what this oil was for but since it was co
mplimentary from Influencer I wanted to try it in some capacity. I used it a
s a cuticle oil and it is fantastic for that purpose. I had no irritation an
d I have a tendency to rub my ...
- (neg) Not recommended Gave me a wicked reaction around my eyes after only
maybe 2 uses - super puffy, red and swollen. It almost looks like I got hit
in the face. I don't really like putting my image out in public but I believ
e the reaction should be seen....
```

Here we can again justify clusters division by topics. Inside the Cluster 0, reviews talk about whether a product "works", breakouts, and value for money, consistent with keywords like product, acne, work, price, didnt, worth. We see both praise ("great product") and frustration about reformulations and side-effects (breakouts, pimples), which explains the only slightly-positive pos_share for this cluster. Next, in the Cluster 1, all examples are about lip balms/oils, focusing on texture (thin vs sticky), hydration longevity, and flavor/scent. Sentiment ranges from "miss for me... makes me feel nauseous" to strong enthusiasm ("absolutely amazing... my go to lip product"), matching the mixed but overall positive pos_share. Regarding the Cluster 2, reviews explicitly mention sensitive, milia-prone, irritated, dry skin, and evaluate how moisturizers/sunscreens perform in daily use. All three samples are clearly positive ("good all purpose", "top daily moisturizer", "underrated... made my skin so glowy"), which is consistent with this cluster's very high positive share. Talking about Cluster 3, every example contains a disclosure like "I received this product in exchange for my honest review", matching the dominant bigrams in this cluster. Within those, tone is uniformly positive about gentleness, moisture, scent, and packaging, which fits the very high pos_share and the interpretation that this cluster is driven by PR/sample campaigns. Next, taking the Cluster 4, reviews describe serums as "game changer", "super hydrating and smooth", "makes my routine easier", which matches keywords love, serum, routine, glow, amazing. Even the negative example ("wanted to love this...

made my face look greasy and caused breakouts") still uses aspirational language, reinforcing that this cluster captures high-engagement, often glowing but sometimes disappointed serum users. Finally, in the Cluster 5 texts focus on eye creams/serums, dark circles, and the delicate eye area, exactly as the top words suggest. Two reviews emphasize gentleness and ritual (even when one repurposes the oil as cuticle oil), while one describes a severe reaction (puffy, red, swollen eyes), which aligns with a generally positive cluster where effectiveness and tolerability around the eyes are key concerns.

Overall, clustering shows that our review corpus is structured into coherent, interpretable topics that align with product types and usage concerns, and that these topics have distinct sentiment profiles.

Supervised Machine Learning

Building on the exploratory analysis and sentiment results, we next apply supervised machine learning methods to model the relationship between review text and customer satisfaction. While lexicon-based sentiment analysis reveals a moderate correlation between textual polarity and star ratings, it does not fully capture the complexity of the language used in customer reviews. By using supervised learning, we allow the models to learn meaningful linguistic patterns directly from the data.

We formulate the prediction task as a binary text classification problem, with the goal of predicting whether a review expresses a positive or negative evaluation of a skincare product. Reviews are represented using TF–IDF features, which capture both term importance and contextual usage across the corpus. In addition to TF–IDF, we include a small set of auxiliary text-level features to capture aspects of review structure and sentiment intensity that are not fully reflected by sparse lexical features alone. Specifically, we add word count and sentence count as proxies for review verbosity and level of elaboration, and we include sentiment polarity as a complementary scalar measure of affective tone derived from TextBlob. These auxiliary variables are treated as supplementary and are standardized before being concatenated with the TF–IDF matrix. This feature design preserves the text-focused nature of the task while providing additional information that may improve classification performance without introducing product-level metadata or potential leakage.

In [49]:
```
df_unique
```

Out[49]:

	review_id	date_published	rating_value	label	name	brand	catego
0	351645103	2025-07-10	3.0	clean	Plumping & Softening Sweet Agave Lip Balm Treatment	ALPYN	lip-balr lip-ca
1	349938731	2025-06-17	5.0	clean	Plumping & Softening Sweet Agave Lip Balm Treatment	ALPYN	lip-balr lip-ca
2	348900301	2025-06-08	5.0	clean	Plumping & Softening Sweet Agave Lip Balm Treatment	ALPYN	lip-balr lip-ca
3	347053222	2025-05-24	4.0	clean	Plumping & Softening Sweet Agave Lip Balm Treatment	ALPYN	lip-balr lip-ca
4	346825636	2025-05-21	3.0	clean	Plumping & Softening Sweet Agave Lip Balm Treatment	ALPYN	lip-balr lip-ca

	review_id	date_published	rating_value	label	name	brand	catego
...	...	...	...	...	...	...	
40169	326736933	2024-12-05	1.0	vegan	Resveratrol 3% + Ferulic Acid 3% Antioxidant Serum for Brightening	The Ordinary	fac seru
40170	319292551	2024-09-19	1.0	vegan	Resveratrol 3% + Ferulic Acid 3% Antioxidant Serum for Brightening	The Ordinary	fac seru
40171	318688071	2024-09-11	5.0	vegan	Resveratrol 3% + Ferulic Acid 3% Antioxidant Serum for Brightening	The Ordinary	fac seru
40172	318343505	2024-09-05	2.0	vegan	Resveratrol 3% + Ferulic Acid 3% Antioxidant Serum for Brightening	The Ordinary	fac seru

	review_id	date_published	rating_value	label	name	brand	catego
40173	317741363	2024-08-29	2.0	vegan	Resveratrol 3% + Ferulic Acid 3% Antioxidant Serum for Brightening	The Ordinary	fac seru

18556 rows × 25 columns

In [50]:
```
X_text = df_unique["processed_review"].astype(str)
y = df_unique["rating_binary"].astype(int)

aux_cols = ["word_count", "sentence_count", "sentiment_polarity"]
X_aux = df_unique[aux_cols].copy()
```

In [51]:
```
X_train_text, X_test_text, y_train, y_test, X_train_aux, X_test_aux = train_
    X_text,
    y,
    X_aux,
    test_size=0.2,
    random_state=42,
    stratify=y
)

print("Train size:", len(X_train_text), "| Test size:", len(X_test_text))
print("\nClass distribution (train):\n", y_train.value_counts())
print("\nClass distribution (test):\n", y_test.value_counts())
```

```
Train size: 14844 | Test size: 3712

Class distribution (train):
 rating_binary
1    10299
0     4545
Name: count, dtype: int64

Class distribution (test):
 rating_binary
1    2575
0    1137
Name: count, dtype: int64
```

In [52]:
```
tfidf = TfidfVectorizer(
    max_df=0.5,
    min_df=10,
    ngram_range=(1, 2),
    max_features=20000
)
```

```
X_train_tfidf = tfidf.fit_transform(X_train_text)
X_test_tfidf = tfidf.transform(X_test_text)

print("\nTF-IDF train shape:", X_train_tfidf.shape)
print("TF-IDF test shape:", X_test_tfidf.shape)
```

```
TF-IDF train shape: (14844, 7290)
TF-IDF test shape: (3712, 7290)
```

In [55]:
```
scaler = StandardScaler()
X_train_aux_scaled = scaler.fit_transform(X_train_aux)
X_test_aux_scaled = scaler.transform(X_test_aux)

X_train_final = hstack([X_train_tfidf, X_train_aux_scaled])
X_test_final = hstack([X_test_tfidf, X_test_aux_scaled])

print("\nFinal train shape (TF-IDF + aux):", X_train_final.shape)
print("Final test shape (TF-IDF + aux):", X_test_final.shape)
```

```
Final train shape (TF-IDF + aux): (14844, 7293)
Final test shape (TF-IDF + aux): (3712, 7293)
```

In preparation for supervised learning, we first define the input variables used in the modeling stage. The processed review text serves as the primary textual input, while the binary rating variable is used as the prediction target. In addition to the textual representation, we extract a small set of auxiliary text-derived numeric features, namely word count, sentence count, and sentiment polarity, which are intended to complement the lexical information captured by TF–IDF.

The dataset is then split into training and test sets using a stratified train–test split, ensuring that the proportion of positive and negative reviews is preserved across both subsets. This step allows for an unbiased evaluation of model performance while maintaining the original class imbalance structure of the data. The TF-IDF vectoriaztion has been already applied in the clustering part, but for the purpose of data leakage prevention, we needed to repeat this step.

Textual features are constructed using TF–IDF vectorization applied to the processed review text. To prevent information leakage, the TF–IDF model is fitted exclusively on the training data and subsequently applied to the test data using the same learned vocabulary and weighting scheme. The vectorization incorporates both unigrams and bigrams and applies frequency-based filtering to remove extremely common and very rare terms, resulting in a high-dimensional sparse representation of the reviews.

The auxiliary numeric features are standardized using z-score normalization, which is necessary to ensure comparability across features and to support models that are sensitive to feature scaling, such as logistic regression and support vector machines. Finally, the standardized auxiliary features are concatenated with the TF–IDF feature matrix, producing a combined feature representation that integrates lexical content with structural and sentiment-related characteristics of the reviews. This final feature matrix is used as input for all supervised learning models to ensure a consistent and comparable modeling framework.

Logistic Regression

In [56]:
```
log_reg = LogisticRegression(
    max_iter=2000,
    class_weight="balanced",
    random_state=42,
    n_jobs=-1
)

log_reg.fit(X_train_final, y_train)
```

Out[56]:
```
▾ LogisticRegression
▸ Parameters
```

To account for the imbalance between positive and negative reviews, we train the logistic regression model using class reweighting, assigning higher importance to the minority class during optimization. Specifically, the model is configured with class_weight = "balanced", which adjusts the contribution of each class to the loss function in proportion to its frequency in the training data. This approach reduces the tendency of the classifier to favor the majority class and improves its ability to correctly identify negative reviews.

In [58]:
```
y_pred_lr = log_reg.predict(X_test_final)
# probabilities
y_proba_lr = log_reg.predict_proba(X_test_final)[:, 1]  # P(class=1)
```

In [59]:
```
# Metrics computation
acc_lr = accuracy_score(y_test, y_pred_lr)

# Use binary metrics with explicit positive label
precision_lr_pos = precision_score(y_test, y_pred_lr, pos_label=1)
recall_lr_pos = recall_score(y_test, y_pred_lr, pos_label=1)
f1_lr_pos = f1_score(y_test, y_pred_lr, pos_label=1)

# Metrics for the negative class
precision_lr_neg = precision_score(y_test, y_pred_lr, pos_label=0)
recall_lr_neg = recall_score(y_test, y_pred_lr, pos_label=0)
f1_lr_neg = f1_score(y_test, y_pred_lr, pos_label=0)

# Confusion matrix
cm_lr = confusion_matrix(y_test, y_pred_lr)

# ROC-AUC
roc_auc_lr = roc_auc_score(y_test, y_proba_lr)

results_lr = {
```

```python
    "model": "Logistic Regression",
    "accuracy": acc_lr,
    "precision_pos": precision_lr_pos,
    "recall_pos": recall_lr_pos,
    "f1_pos": f1_lr_pos,
    "precision_neg": precision_lr_neg,
    "recall_neg": recall_lr_neg,
    "f1_neg": f1_lr_neg,
    "roc_auc": roc_auc_lr,
    "confusion_matrix": cm_lr,
    "y_pred": y_pred_lr,
    "y_proba": y_proba_lr
}

print("Logistic Regression results:")
print("Accuracy:", round(results_lr["accuracy"], 4))
print("F1 (pos):", round(results_lr["f1_pos"], 4), "| F1 (neg):", round(resu
print("ROC-AUC:", round(results_lr["roc_auc"], 4))
print("Confusion matrix:\n", results_lr["confusion_matrix"])
print("\nClassification report:\n", classification_report(y_test, y_pred_lr,
```

```
Logistic Regression results:
Accuracy: 0.8955
F1 (pos): 0.9223 | F1 (neg): 0.8402
ROC-AUC: 0.9539
Confusion matrix:
 [[1020  117]
 [ 271 2304]]

Classification report:
               precision    recall  f1-score   support

           0     0.7901    0.8971    0.8402      1137
           1     0.9517    0.8948    0.9223      2575

    accuracy                         0.8955      3712
   macro avg     0.8709    0.8959    0.8813      3712
weighted avg     0.9022    0.8955    0.8972      3712
```

The logistic regression model demonstrates strong overall performance in predicting review sentiment based on textual features. The model achieves an accuracy of 0.896, indicating that nearly 90% of reviews in the test set are classified correctly. While accuracy alone can be misleading in the presence of class imbalance, additional evaluation metrics confirm that the model performs consistently well across both classes.

The ROC–AUC score of 0.954 indicates excellent separability between positive and negative reviews. This suggests that the model is highly effective at ranking reviews according to their likelihood of being positive, and that the learned decision boundary captures meaningful distinctions in the underlying text representations. Such a high ROC–AUC value implies that the model is robust across different classification thresholds and is not overly sensitive to the chosen decision cutoff.

Class-specific performance further highlights the strengths and limitations of the model. For positive reviews, the model achieves a high F1-score of 0.922, supported by strong precision (0.952) and recall (0.895). This indicates that the classifier is both accurate in identifying positive reviews and able to recover the majority of them. Given that positive reviews constitute the majority class, this result confirms that the model does not simply overfit to the dominant class but learns informative lexical patterns associated with customer satisfaction.

Importantly, the model also performs well on the negative review class, which is the minority class in the dataset. The F1-score of 0.840 reflects a balanced trade-off between precision (0.790) and recall (0.897). The high recall for negative reviews indicates that the model successfully identifies most dissatisfied customers, which is particularly relevant from a business perspective where failing to detect negative feedback can have significant consequences. The slightly lower precision suggests that some positive reviews are misclassified as negative, a pattern that reflects the inherent ambiguity present in mixed or nuanced customer opinions.

The confusion matrix provides additional insight into the model's behavior. Of the 1,137 negative reviews in the test set, 1,020 are correctly classified, while 117 are misclassified as positive. Conversely, 271 positive reviews are incorrectly predicted as negative. This asymmetry is consistent with the model's emphasis on recall for the negative class due to class reweighting, which intentionally prioritizes the detection of negative sentiment at the expense of a small increase in false positives.

To further improve model performance and assess the robustness of the results, we perform hyperparameter tuning of the logistic regression model.

In [70]:
```
f1_neg_scorer = make_scorer(f1_score, pos_label=0)
```

Because negative reviews represent the minority class and are of particular importance from a business perspective, we focus on optimizing model performance for this class. Emphasizing negative-class performance reduces the risk of overlooking dissatisfied customers and provides more actionable insights for product evaluation. To capture this objective, we use the F1-score for the negative class as the primary optimization metric during model tuning. The F1-score provides a balanced measure of precision and recall, ensuring that the model not only identifies a high proportion of negative reviews but also limits the number of false positive predictions. This metric is therefore well suited to imbalanced classification settings where accuracy alone may be misleading.

In [71]:
```
param_grid = {
    "penalty": ["l1", "l2"],
    "C": [0.01, 0.1, 1, 10, 100],
    "solver": ["liblinear"]
}
```

```
cv = StratifiedKFold(n_splits=5, shuffle=True, random_state=42)

grid_lr = GridSearchCV(
    estimator=log_reg,
    param_grid=param_grid,
    scoring=f1_neg_scorer,   # optimize minority/negative class performance
    cv=cv,
    n_jobs=-1,
    verbose=1,
    refit=True
)
```

In [72]:
```
grid_lr.fit(X_train_final, y_train)

print("\nBest parameters:", grid_lr.best_params_)
print("Best CV F1 (negative class):", round(grid_lr.best_score_, 4))

# Evaluate best model on test set
best_lr = grid_lr.best_estimator_

y_pred_lr_tuned = best_lr.predict(X_test_final)
y_proba_lr_tuned = best_lr.predict_proba(X_test_final)[:, 1]

cm_lr_tuned = confusion_matrix(y_test, y_pred_lr_tuned)

acc_lr_tuned = accuracy_score(y_test, y_pred_lr_tuned)

precision_neg_lr_tuned = precision_score(y_test, y_pred_lr_tuned, pos_label=
recall_neg_lr_tuned = recall_score(y_test, y_pred_lr_tuned, pos_label=0)
f1_neg_lr_tuned = f1_score(y_test, y_pred_lr_tuned, pos_label=0)

precision_pos_lr_tuned = precision_score(y_test, y_pred_lr_tuned, pos_label=
recall_pos_lr_tuned = recall_score(y_test, y_pred_lr_tuned, pos_label=1)
f1_pos_lr_tuned = f1_score(y_test, y_pred_lr_tuned, pos_label=1)

roc_auc_lr_tuned = roc_auc_score(y_test, y_proba_lr_tuned)

results_lr_tuned = {
    "model": "Logistic Regression (tuned)",
    "best_params": grid_lr.best_params_,
    "cv_best_f1_neg": grid_lr.best_score_,
    "accuracy": acc_lr_tuned,
    "precision_neg": precision_neg_lr_tuned,
    "recall_neg": recall_neg_lr_tuned,
    "f1_neg": f1_neg_lr_tuned,
    "precision_pos": precision_pos_lr_tuned,
    "recall_pos": recall_pos_lr_tuned,
    "f1_pos": f1_pos_lr_tuned,
    "roc_auc": roc_auc_lr_tuned,
    "confusion_matrix": cm_lr_tuned,
    "y_pred": y_pred_lr_tuned,
    "y_proba": y_proba_lr_tuned
}

print("\nTuned Logistic Regression (Test set):")
print("Accuracy:", round(results_lr_tuned["accuracy"], 4))
```

```
print("F1 (neg):", round(results_lr_tuned["f1_neg"], 4), "| F1 (pos):", rour
print("ROC-AUC:", round(results_lr_tuned["roc_auc"], 4))
print("Confusion matrix:\n", results_lr_tuned["confusion_matrix"])
print("\nClassification report:\n", classification_report(y_test, y_pred_lr_
```

```
Fitting 5 folds for each of 10 candidates, totalling 50 fits

Best parameters: {'C': 10, 'penalty': 'l2', 'solver': 'liblinear'}
Best CV F1 (negative class): 0.8549

Tuned Logistic Regression (Test set):
Accuracy: 0.8976
F1 (neg): 0.8403 | F1 (pos): 0.9247
ROC-AUC: 0.9562
Confusion matrix:
 [[1000  137]
 [ 243 2332]]

Classification report:
               precision    recall  f1-score   support

           0     0.8045    0.8795    0.8403      1137
           1     0.9445    0.9056    0.9247      2575

    accuracy                         0.8976      3712
   macro avg     0.8745    0.8926    0.8825      3712
weighted avg     0.9016    0.8976    0.8988      3712
```

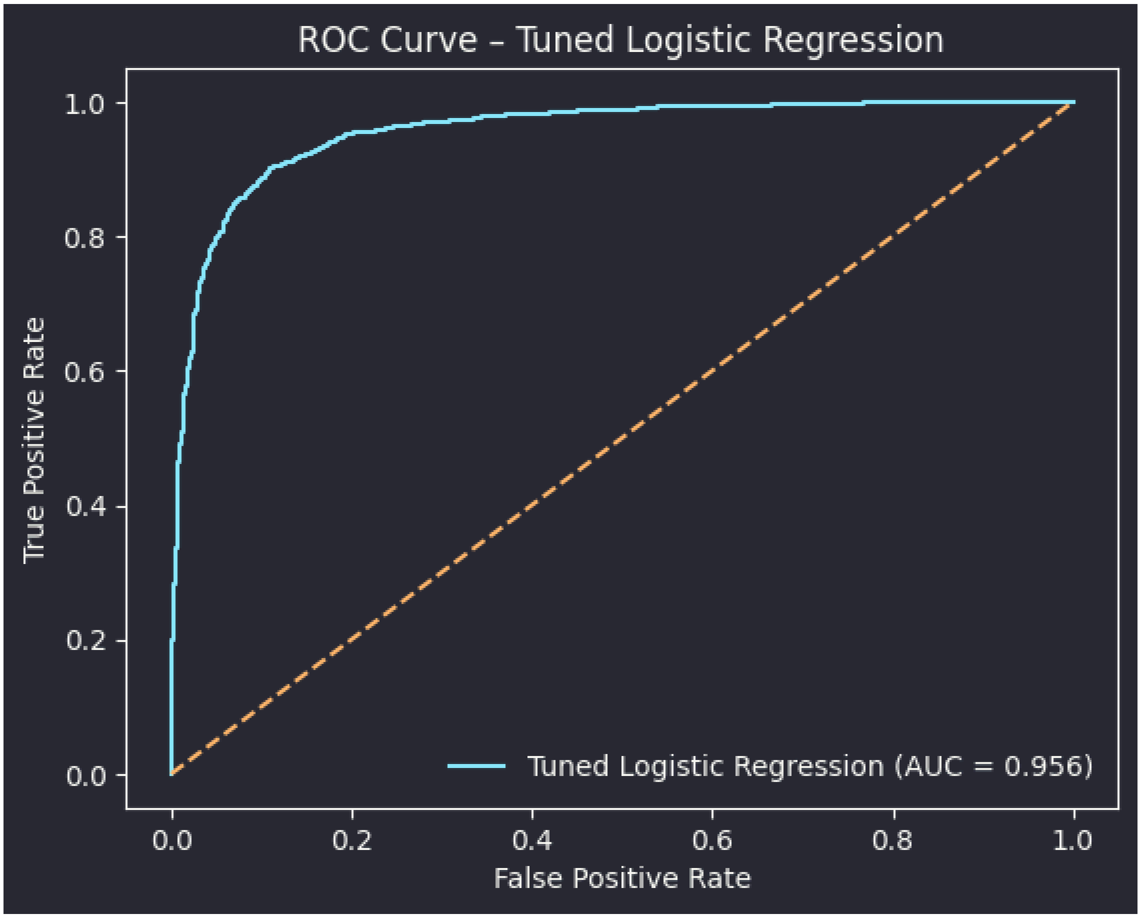
On the test set, the tuned model achieves an accuracy of 0.898, representing a small improvement over the untuned baseline. More importantly, the ROC–AUC score increases to 0.956, confirming that the tuned model exhibits slightly stronger class separability and improved ranking performance across classification thresholds. This suggests that the tuning process enhances the model’s ability to distinguish between positive and negative reviews beyond a single decision boundary.

With respect to class-specific performance, the tuned model maintains a high F1-score for the positive class (0.925), supported by strong precision (0.945) and recall (0.906). This indicates that tuning does not compromise the model’s ability to correctly identify satisfied customers. At the same time, performance for the negative class remains stable, with an F1-score of 0.840, which is comparable to the untuned model. Precision for negative reviews increases slightly, while recall decreases marginally, reflecting a more balanced trade-off between false positives and false negatives.

In [74]:
```
fpr, tpr, thresholds = roc_curve(y_test, y_proba_lr_tuned)
roc_auc = auc(fpr, tpr)

# Plot ROC curve
plt.figure()
plt.plot(fpr, tpr, label=f"Tuned Logistic Regression (AUC = {roc_auc:.3f})")
plt.plot([0, 1], [0, 1], linestyle="--")
plt.xlabel("False Positive Rate")
```

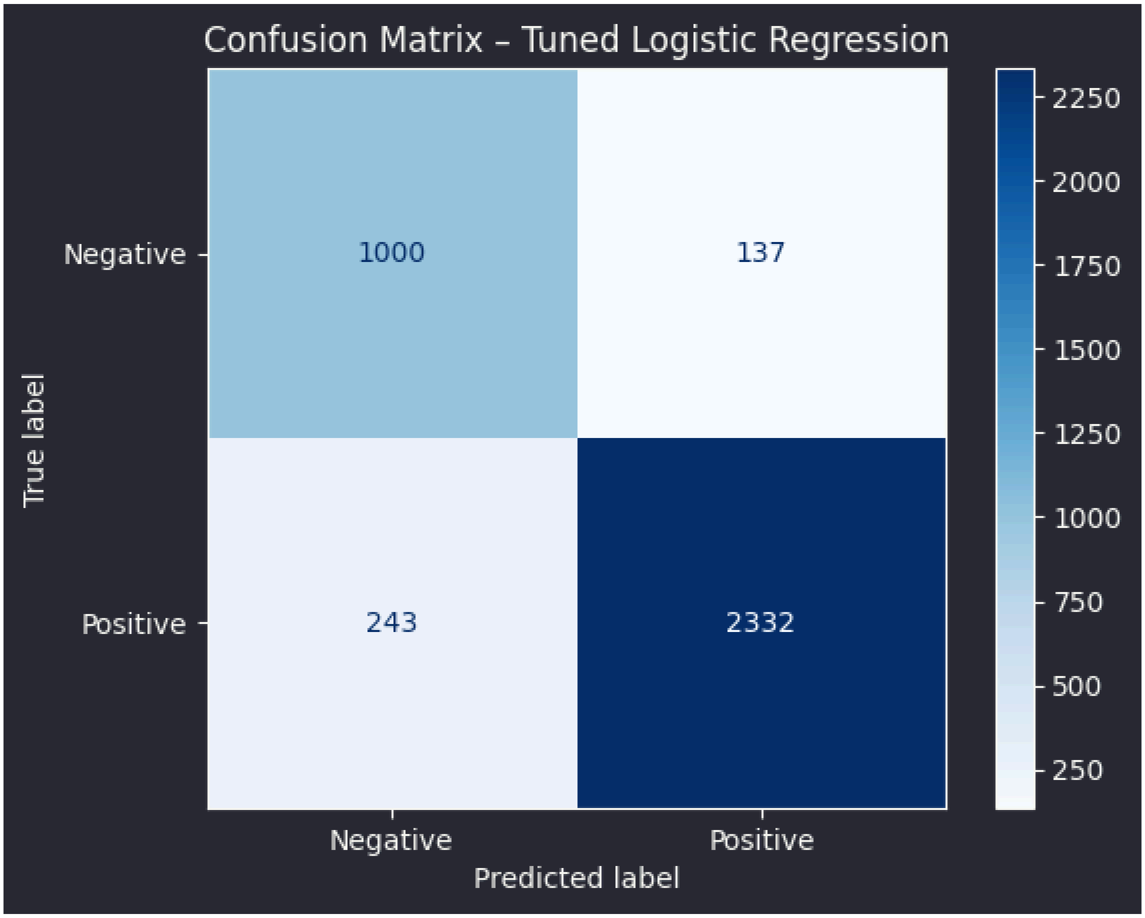
```
plt.ylabel("True Positive Rate")
plt.title("ROC Curve – Tuned Logistic Regression")
plt.legend(loc="lower right")
plt.show()
```



In [75]:

```
disp = ConfusionMatrixDisplay(
    confusion_matrix=cm_lr_tuned,
    display_labels=["Negative", "Positive"]
)

disp.plot(cmap="Blues", values_format="d")
plt.title("Confusion Matrix – Tuned Logistic Regression")
plt.show()
```



The confusion matrix further illustrates this shift in behavior. Compared to the baseline model, the tuned classifier produces fewer false negatives for positive reviews, while accepting a small increase in false positives for the negative class. This pattern suggests that the tuning process slightly refines the decision boundary rather than fundamentally altering the model's behavior. Importantly, the model continues to identify the majority of negative reviews correctly, aligning with the project's objective of detecting dissatisfied customers.

In [ ]:

```
tfidf_feature_names = np.array(tfidf.get_feature_names_out())
n_tfidf_features = len(tfidf_feature_names)
coef = best_lr.coef_[0][:n_tfidf_features]

top_positive_idx = np.argsort(coef)[-15:]
top_negative_idx = np.argsort(coef)[:15]

top_positive_words = tfidf_feature_names[top_positive_idx]
top_negative_words = tfidf_feature_names[top_negative_idx]

print("Top positive words:")
print(top_positive_words)

print("\nTop negative words:")
print(top_negative_words)
```

```
Top positive words:
['always' 'wow' 'doesnt cause' 'softer' 'highly recommend' 'doesnt burn'
 'staple' 'without' 'soft' 'perfect' 'helped' 'amazing' 'love' 'obsessed'
 'must']

Top negative words:
['wanted love' 'okay' 'broke' 'meh' 'didnt' 'returned' 'doesnt work'
 'better' 'return' 'unfortunately' 'returning' 'burn' 'caused' 'pas'
 'nothing']
```

The influential terms identified by the tuned logistic regression model are consistent with the patterns observed in the earlier exploratory, sentiment-based, and clustering analyses. Positive coefficients are associated with highly expressive and affective terms such as “love”, “amazing”, “perfect” and “highly recommend”, which align with the strong positive sentiment detected in reviews with high polarity scores.

Conversely, negative coefficients correspond to terms such as “didn’t”, “doesn’t work”, “broke”, “burn”, and “returned”, reflecting themes of dissatisfaction and product failure previously identified in the unsupervised analysis. The presence of ambivalent terms such as “meh” and “okay” further supports the decision to group neutral or weakly positive evaluations with the negative class.

Random Forest

To assess whether an ensemble-based approach can improve performance beyond linear models, we apply a Random Forest classifier and directly focus on hyperparameter tuning, rather than evaluating an untuned baseline. Consistent with the logistic regression setup, particular emphasis is placed on the negative review class, which represents the minority class and is of greater relevance from a business perspective. Accordingly, model selection is guided by the F1-score of the negative class, ensuring a balanced trade-off between precision and recall for dissatisfied customer reviews.

Class imbalance is further addressed by incorporating sample weights during model training, assigning higher importance to negative reviews. Hyperparameter optimization is conducted using RandomizedSearchCV with stratified cross-validation, preserving class proportions across folds. The tuning process explores key Random Forest parameters related to model complexity and generalization, including the number of trees, tree depth, split and leaf size constraints, feature subsampling strategies, and bootstrap sampling. The resulting best-performing configuration is retained as the tuned Random Forest model for subsequent evaluation on the test set.

In [ ]:
```
f1_neg_scorer = make_scorer(f1_score, pos_label=0)
sample_w = compute_sample_weight(class_weight="balanced", y=y_train)

rf_base = RandomForestClassifier(
    random_state=42,
    n_jobs=-1
```

```
)

param_dist = {
    "n_estimators": [300, 500, 800],
    "max_depth": [None, 10, 20, 40],
    "min_samples_split": [2, 5, 10],
    "min_samples_leaf": [1, 2, 5],
    "max_features": ["sqrt", "log2", 0.2, 0.5],
    "bootstrap": [True, False]
}

cv = StratifiedKFold(n_splits=5, shuffle=True, random_state=42)

rf_search = RandomizedSearchCV(
    estimator=rf_base,
    param_distributions=param_dist,
    n_iter=20,
    scoring=f1_neg_scorer,     # focus on negative class
    cv=cv,
    n_jobs=-1,
    verbose=1,
    random_state=42,
    refit=True
)

# Fit tuning
rf_search.fit(X_train_final, y_train, sample_weight=sample_w)

print("Best RF parameters:", rf_search.best_params_)
print("Best CV F1 (negative class):", round(rf_search.best_score_, 4))

best_rf = rf_search.best_estimator_
```

```
Fitting 5 folds for each of 20 candidates, totalling 100 fits
```

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Best RF parameters: {'n_estimators': 800, 'min_samples_split': 10, 'min_samp
les_leaf': 5, 'max_features': 'log2', 'max_depth': None, 'bootstrap': False}
Best CV F1 (negative class): 0.8766
```

In [80]:

```
# Predictions
y_pred_rf_tuned = best_rf.predict(X_test_final)

# Probabilities for ROC-AUC
y_proba_rf_tuned = best_rf.predict_proba(X_test_final)[:, 1]

# Confusion matrix
cm_rf_tuned = confusion_matrix(y_test, y_pred_rf_tuned)

# Metrics
```

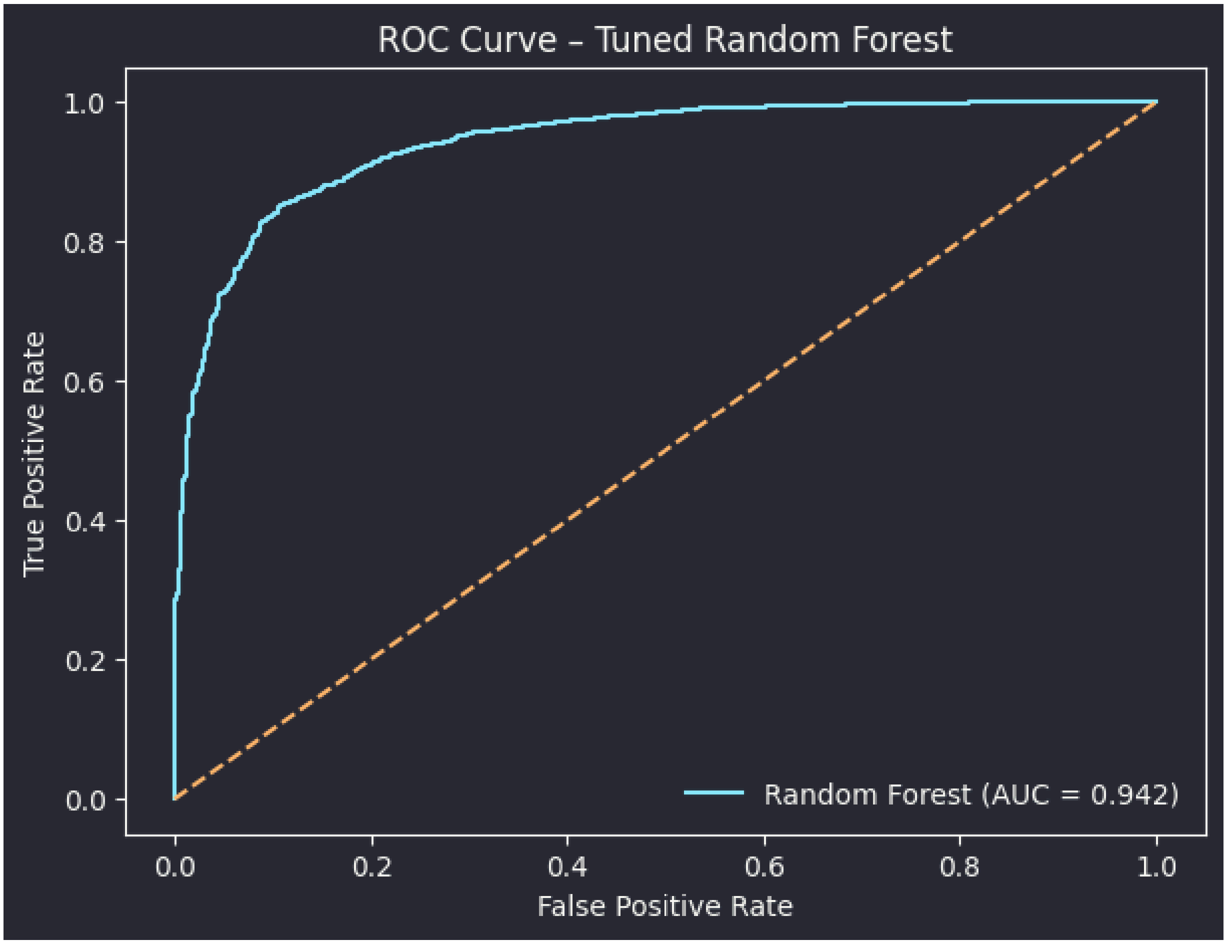
```python
acc_rf_tuned = accuracy_score(y_test, y_pred_rf_tuned)

precision_rf_neg = precision_score(y_test, y_pred_rf_tuned, pos_label=0)
recall_rf_neg = recall_score(y_test, y_pred_rf_tuned, pos_label=0)
f1_rf_neg = f1_score(y_test, y_pred_rf_tuned, pos_label=0)

precision_rf_pos = precision_score(y_test, y_pred_rf_tuned, pos_label=1)
recall_rf_pos = recall_score(y_test, y_pred_rf_tuned, pos_label=1)
f1_rf_pos = f1_score(y_test, y_pred_rf_tuned, pos_label=1)

roc_auc_rf_tuned = roc_auc_score(y_test, y_proba_rf_tuned)

results_rf_tuned = {
    "model": "Random Forest (tuned)",
    "best_params": rf_search.best_params_,
    "cv_best_f1_neg": rf_search.best_score_,
    "accuracy": acc_rf_tuned,
    "precision_neg": precision_rf_neg,
    "recall_neg": recall_rf_neg,
    "f1_neg": f1_rf_neg,
    "precision_pos": precision_rf_pos,
    "recall_pos": recall_rf_pos,
    "f1_pos": f1_rf_pos,
    "roc_auc": roc_auc_rf_tuned,
    "confusion_matrix": cm_rf_tuned,
    "y_pred": y_pred_rf_tuned,
    "y_proba": y_proba_rf_tuned
}

print("\nTuned Random Forest (Test set):")
print("Accuracy:", round(results_rf_tuned["accuracy"], 4))
print("F1 (neg):", round(results_rf_tuned["f1_neg"], 4), "| F1 (pos):", rour
print("ROC-AUC:", round(results_rf_tuned["roc_auc"], 4))
print("Confusion matrix:\n", results_rf_tuned["confusion_matrix"])
print("\nClassification report:\n", classification_report(y_test, y_pred_rf_
```

```
Tuned Random Forest (Test set):
Accuracy: 0.8685
F1 (neg): 0.7983 | F1 (pos): 0.9025
ROC-AUC: 0.9417
Confusion matrix:
 [[ 966  171]
 [ 317 2258]]

Classification report:
               precision    recall  f1-score   support

           0     0.7529    0.8496    0.7983      1137
           1     0.9296    0.8769    0.9025      2575

    accuracy                         0.8685      3712
   macro avg     0.8413    0.8632    0.8504      3712
weighted avg     0.8755    0.8685    0.8706      3712
```

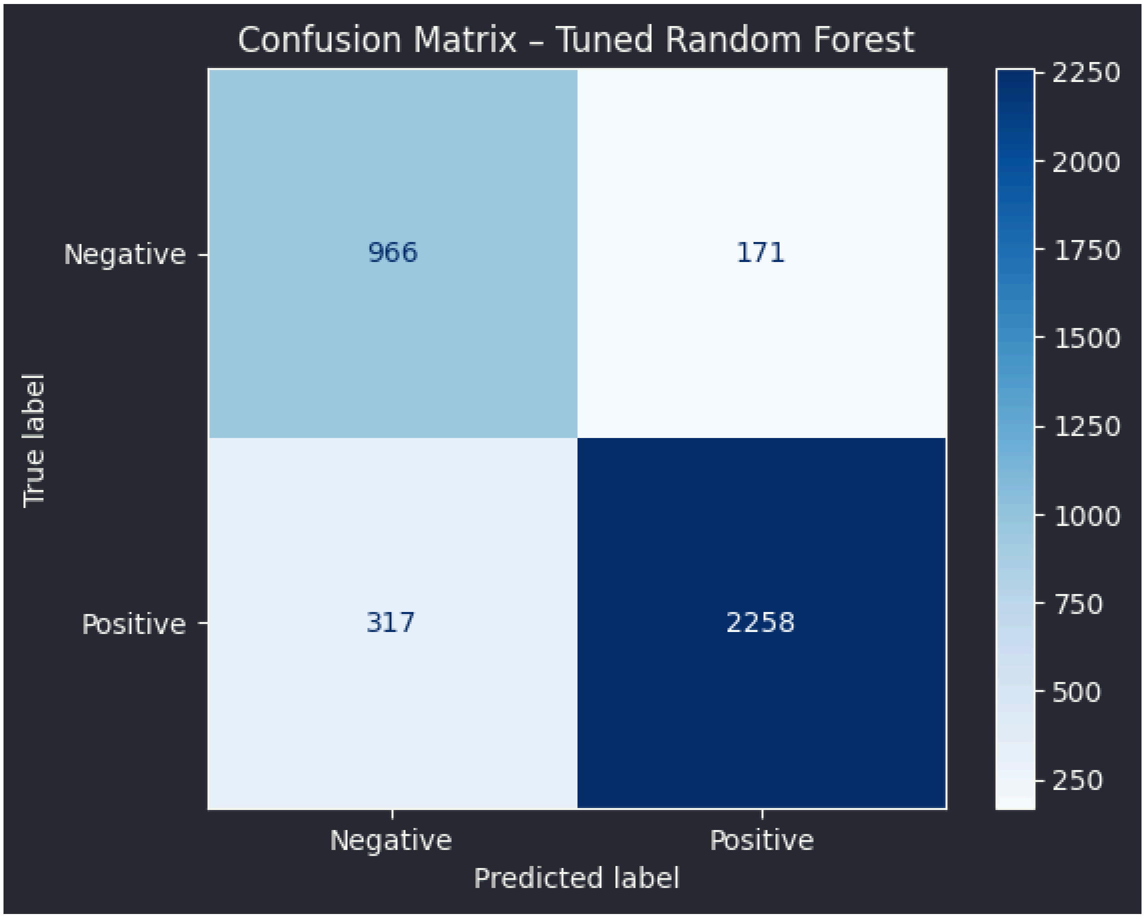
The tuned Random Forest model achieves a solid overall performance on the test set, with an accuracy of 0.869 and a ROC–AUC of 0.942, indicating strong class separability across decision thresholds. These results confirm that the ensemble model is able to capture non-linear patterns in the textual feature space and distinguish effectively between positive and negative reviews. In terms of class specific performance, the model maintains a high F1-score for positive reviews (0.903), supported by strong precision (0.930) and recall (0.877). This indicates that the Random Forest reliably identifies satisfied customers while maintaining a low rate of false positive predictions for the positive class.

Performance on the negative class, which represents the minority and the primary focus of model tuning, is more moderate. The negative-class F1-score of 0.798 reflects a trade-off between precision (0.753) and recall (0.850). The relatively high recall suggests that the model successfully identifies a large proportion of dissatisfied customers, while the lower precision indicates that some positive reviews are misclassified as negative. This behaviour is consistent with the tuning strategy, which prioritizes recall for the negative class to reduce the risk of overlooking negative feedback.

In [83]:
```
y_proba_rf = best_rf.predict_proba(X_test_final)[:, 1]

# ROC curve
fpr, tpr, thresholds = roc_curve(y_test, y_proba_rf)
roc_auc = auc(fpr, tpr)

plt.figure(figsize=(7, 5))
plt.plot(fpr, tpr, label=f"Random Forest (AUC = {roc_auc:.3f})")
plt.plot([0, 1], [0, 1], linestyle="--")
plt.xlabel("False Positive Rate")
plt.ylabel("True Positive Rate")
plt.title("ROC Curve – Tuned Random Forest")
plt.legend(loc="lower right")
plt.show()
```



In [84]:
```
y_pred_rf = best_rf.predict(X_test_final)

# Confusion matrix
cm_rf = confusion_matrix(y_test, y_pred_rf)

disp = ConfusionMatrixDisplay(
    confusion_matrix=cm_rf,
    display_labels=["Negative", "Positive"]
)

disp.plot(cmap="Blues", values_format="d")
plt.title("Confusion Matrix – Tuned Random Forest")
plt.show()
```



The confusion matrix further illustrates this pattern. The model correctly classifies 966 negative and 2258 positive reviews, while misclassifying 171 negative reviews as positive and 317 positive reviews as negative. Compared to the logistic regression model, the Random Forest exhibits a slightly higher tendency to misclassify positive reviews as negative, resulting in reduced precision for the negative class.

SVC

As a final supervised learning approach, we apply a Support Vector Classifier (SVC) with a linear kernel to the binary sentiment classification task. Consistent with the previous models, class imbalance is addressed through class weighting, and hyperparameter tuning is performed using cross-validation with a focus on improving performance for the negative class. This allows us to evaluate whether a margin-based classifier such as SVC can provide competitive performance compared to logistic regression and ensemble-based methods when applied to high-dimensional TF–IDF text representations.

In [87]:
```
f1_neg_scorer = make_scorer(f1_score, pos_label=0)

svc = LinearSVC(
    class_weight="balanced",
    random_state=42
)
```

```python
param_grid = {
    "C": [0.01, 0.1, 1, 10, 100]
}

cv = StratifiedKFold(n_splits=5, shuffle=True, random_state=42)

svc_search = GridSearchCV(
    estimator=svc,
    param_grid=param_grid,
    scoring=f1_neg_scorer,     # focus on negative class
    cv=cv,
    n_jobs=-1,
    verbose=1,
    refit=True
)

svc_search.fit(X_train_final, y_train)

print("Best SVM parameters:", svc_search.best_params_)
print("Best CV F1 (negative class):", round(svc_search.best_score_, 4))

best_svc = svc_search.best_estimator_
```

```
Fitting 5 folds for each of 5 candidates, totalling 25 fits
Best SVM parameters: {'C': 1}
Best CV F1 (negative class): 0.8502
```

In [88]:

```python
y_pred_svc = best_svc.predict(X_test_final)

y_score_svc = best_svc.decision_function(X_test_final)

cm_svc = confusion_matrix(y_test, y_pred_svc)

acc_svc = accuracy_score(y_test, y_pred_svc)

precision_svc_neg = precision_score(y_test, y_pred_svc, pos_label=0)
recall_svc_neg = recall_score(y_test, y_pred_svc, pos_label=0)
f1_svc_neg = f1_score(y_test, y_pred_svc, pos_label=0)

precision_svc_pos = precision_score(y_test, y_pred_svc, pos_label=1)
recall_svc_pos = recall_score(y_test, y_pred_svc, pos_label=1)
f1_svc_pos = f1_score(y_test, y_pred_svc, pos_label=1)

roc_auc_svc = roc_auc_score(y_test, y_score_svc)

results_svc_tuned = {
    "model": "Linear SVM (tuned)",
    "best_params": svc_search.best_params_,
    "cv_best_f1_neg": svc_search.best_score_,
    "accuracy": acc_svc,
    "precision_neg": precision_svc_neg,
    "recall_neg": recall_svc_neg,
    "f1_neg": f1_svc_neg,
    "precision_pos": precision_svc_pos,
    "recall_pos": recall_svc_pos,
    "f1_pos": f1_svc_pos,
```

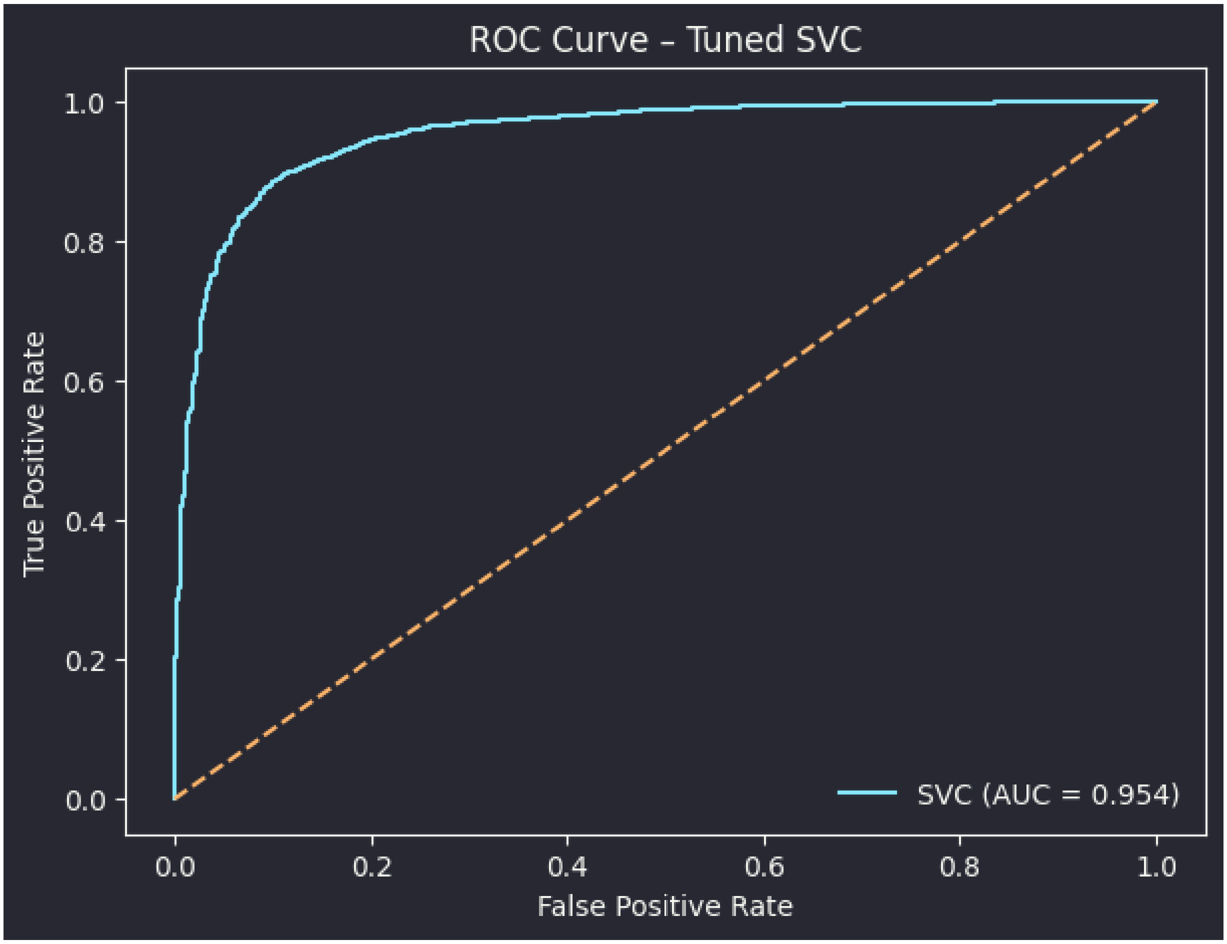
```
    "roc_auc": roc_auc_svc,
    "confusion_matrix": cm_svc,
    "y_pred": y_pred_svc,
    "y_score": y_score_svc
}

print("\nTuned Linear SVM (Test set):")
print("Accuracy:", round(results_svc_tuned["accuracy"], 4))
print("F1 (neg):", round(results_svc_tuned["f1_neg"], 4), "| F1 (pos):", rou
print("ROC-AUC:", round(results_svc_tuned["roc_auc"], 4))
print("Confusion matrix:\n", results_svc_tuned["confusion_matrix"])
print("\nClassification report:\n", classification_report(y_test, y_pred_svc
```

```
Tuned Linear SVM (Test set):
Accuracy: 0.8952
F1 (neg): 0.8359 | F1 (pos): 0.923
ROC-AUC: 0.9544
Confusion matrix:
 [[ 991  146]
 [ 243 2332]]

Classification report:
               precision    recall  f1-score   support

           0     0.8031    0.8716    0.8359      1137
           1     0.9411    0.9056    0.9230      2575

    accuracy                         0.8952      3712
   macro avg     0.8721    0.8886    0.8795      3712
weighted avg     0.8988    0.8952    0.8963      3712
```

The tuned Linear SVC performs well on the test set, with an accuracy of 0.895 and a ROC–AUC of 0.954, showing that the model can clearly distinguish between positive and negative reviews. This suggests that using a linear SVC together with a TF–IDF text representation is effective for capturing sentiment-related information in customer reviews.

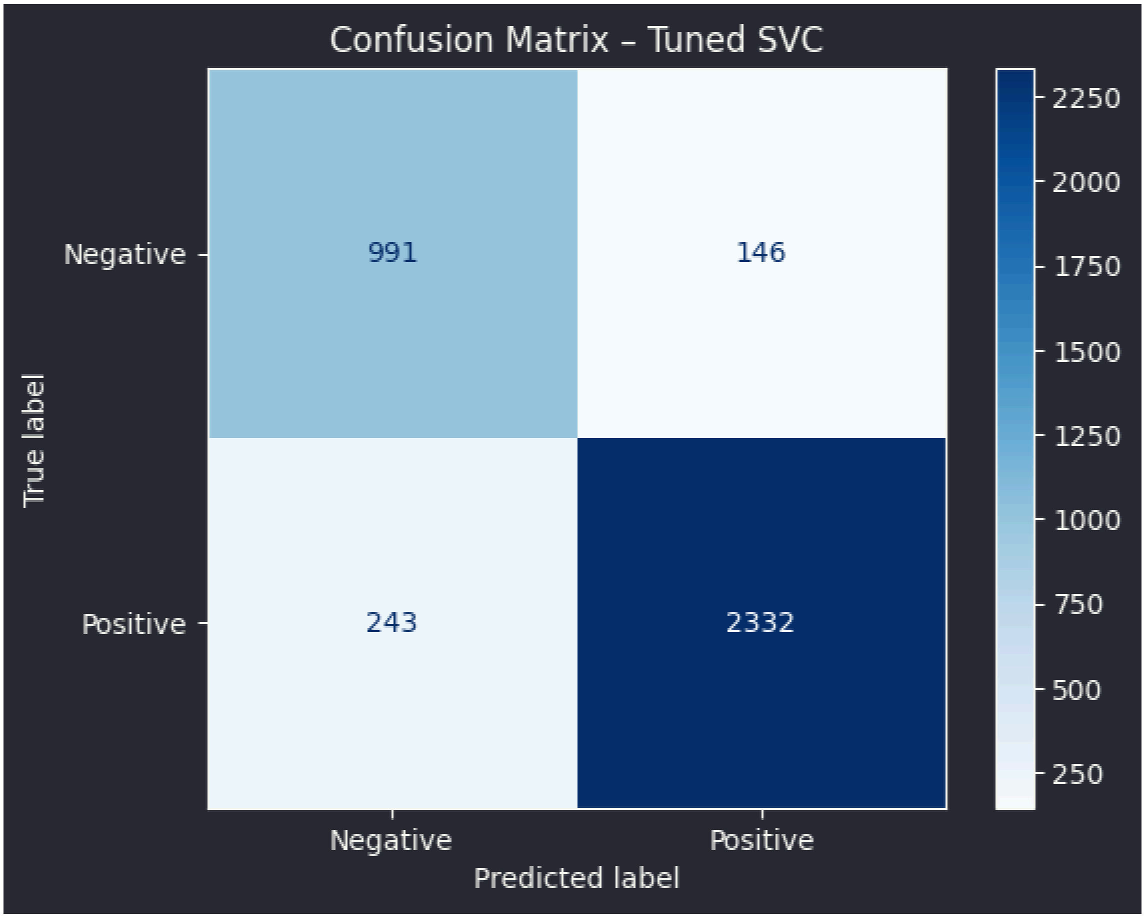
In [ ]:

```
# Decision scores
y_score_svc = best_svc.decision_function(X_test_final)

# ROC curve
fpr, tpr, thresholds = roc_curve(y_test, y_score_svc)
roc_auc = auc(fpr, tpr)

plt.figure(figsize=(7, 5))
plt.plot(fpr, tpr, label=f"SVC (AUC = {roc_auc:.3f})")
plt.plot([0, 1], [0, 1], linestyle="--")
plt.xlabel("False Positive Rate")
plt.ylabel("True Positive Rate")
plt.title("ROC Curve – Tuned SVC")
plt.legend(loc="lower right")
plt.show()
```



In [90]:

```
# Predictions
y_pred_svc = best_svc.predict(X_test_final)

# Confusion matrix
cm_svc = confusion_matrix(y_test, y_pred_svc)

disp = ConfusionMatrixDisplay(
    confusion_matrix=cm_svc,
    display_labels=["Negative", "Positive"]
)

disp.plot(cmap="Blues", values_format="d")
plt.title("Confusion Matrix – Tuned SVC")
plt.show()
```



slightly higher tendency to label borderline cases as negative. Compared to the Random Forest, the Linear SVC achieves a better balance between precision and recall for the negative class, and its performance is very close to that of logistic regression. This suggests that linear models are particularly well suited for this task, as the sentiment signal in the review text appears to be largely linearly separable. Overall, the Linear SVC provides a strong and reliable alternative to logistic regression, while offering similar predictive performance and robustness.

Models' Comparison

After training and tuning the individual supervised learning models, we compare their performance to better understand their relative strengths and weaknesses. Logistic regression, Random Forest, and Linear SVC are evaluated using the same test set and a consistent set of performance metrics, with particular attention paid to the negative class due to class imbalance and its business relevance. This comparison allows us to assess how different modeling approaches handle sentiment classification and to identify which model provides the most balanced and reliable performance for this task.

In [91]:
```
comparison_df = pd.DataFrame([
    {
        "Model": "Logistic Regression",
        "Accuracy": results_lr_tuned["accuracy"],
```

```
        "F1 (Negative)": results_lr_tuned["f1_neg"],
        "F1 (Positive)": results_lr_tuned["f1_pos"],
        "ROC-AUC": results_lr_tuned["roc_auc"]
    },
    {
        "Model": "Random Forest",
        "Accuracy": results_rf_tuned["accuracy"],
        "F1 (Negative)": results_rf_tuned["f1_neg"],
        "F1 (Positive)": results_rf_tuned["f1_pos"],
        "ROC-AUC": results_rf_tuned["roc_auc"]
    },
    {
        "Model": "Linear SVC",
        "Accuracy": results_svc_tuned["accuracy"],
        "F1 (Negative)": results_svc_tuned["f1_neg"],
        "F1 (Positive)": results_svc_tuned["f1_pos"],
        "ROC-AUC": results_svc_tuned["roc_auc"]
    }
])

comparison_df
```

Out[91]:

	Model	Accuracy	F1 (Negative)	F1 (Positive)	ROC-AUC
0	Logistic Regression	0.897629	0.840336	0.924663	0.956157
1	Random Forest	0.868534	0.798347	0.902478	0.941666
2	Linear SVC	0.895205	0.835934	0.923016	0.954431

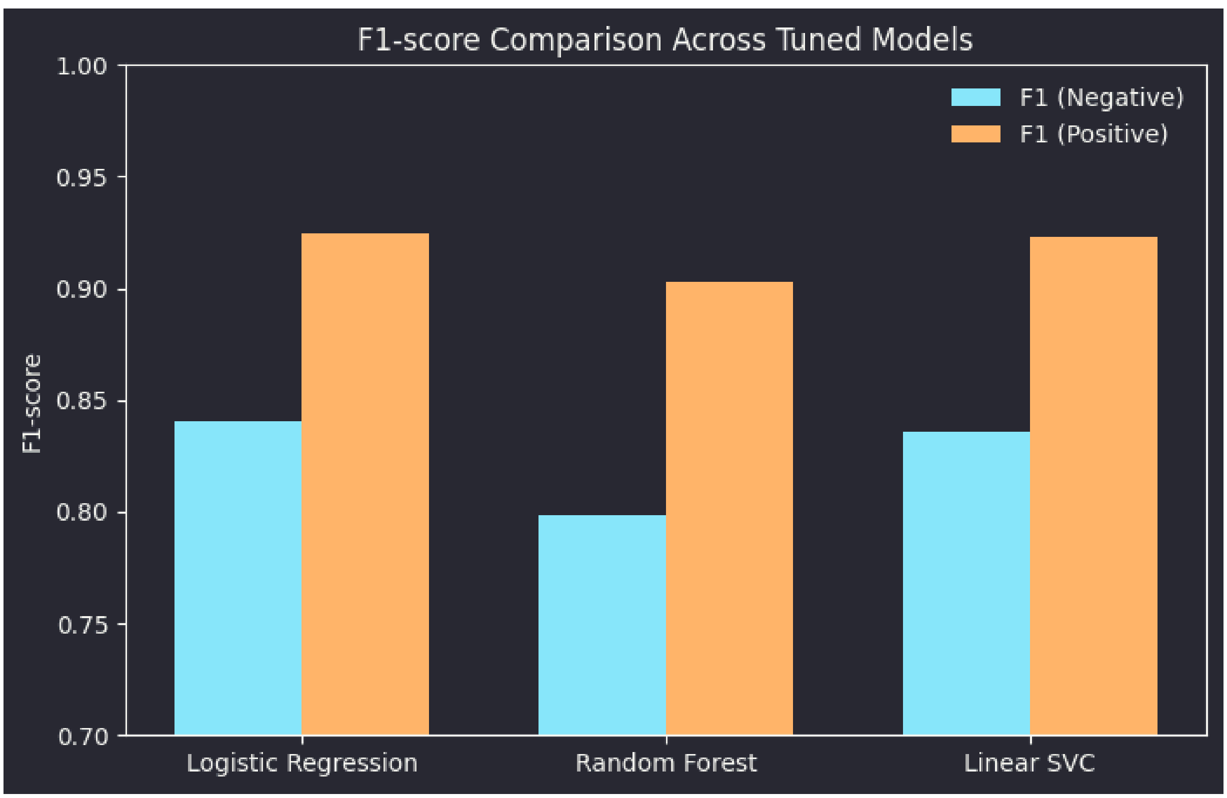
The comparison across the three tuned models highlights clear differences in how well each approach handles the sentiment classification task. Overall, the results suggest that linear models are better suited to this problem than the ensemble-based Random Forest, particularly when minority-class performance is a priority. Both logistic regression and Linear SVC show strong and consistent behavior, indicating that the sentiment signal in the TF–IDF feature space is largely linear and does not require complex non-linear decision boundaries.

Logistic regression emerges as the most balanced model across all evaluation criteria. It combines strong overall performance with reliable detection of negative reviews, while maintaining high performance for positive reviews. This balance makes it especially suitable in a setting where correctly identifying dissatisfied customers is important, but excessive false alarms should be avoided. The interpretability of logistic regression further strengthens its appeal, as the model allows direct inspection of influential words contributing to predictions.

The Linear SVC performs very similarly to logistic regression, confirming that margin-based linear classifiers are also effective for high-dimensional text data. Its results suggest a slightly more conservative decision boundary, which leads to behavior comparable to logistic regression but with subtle differences in how borderline cases are handled. In practice, this means that Linear SVC offers a robust alternative when probabilistic outputs are not required, while still achieving competitive performance.

In contrast, the Random Forest model underperforms relative to the linear approaches. Although it captures non-linear patterns and shows good overall predictive ability, it struggles more with minority-class detection and introduces additional complexity without clear performance gains. This suggests that ensemble-based methods may be less well suited for sparse, high-dimensional TF–IDF representations, where linear models can already separate the classes effectively.

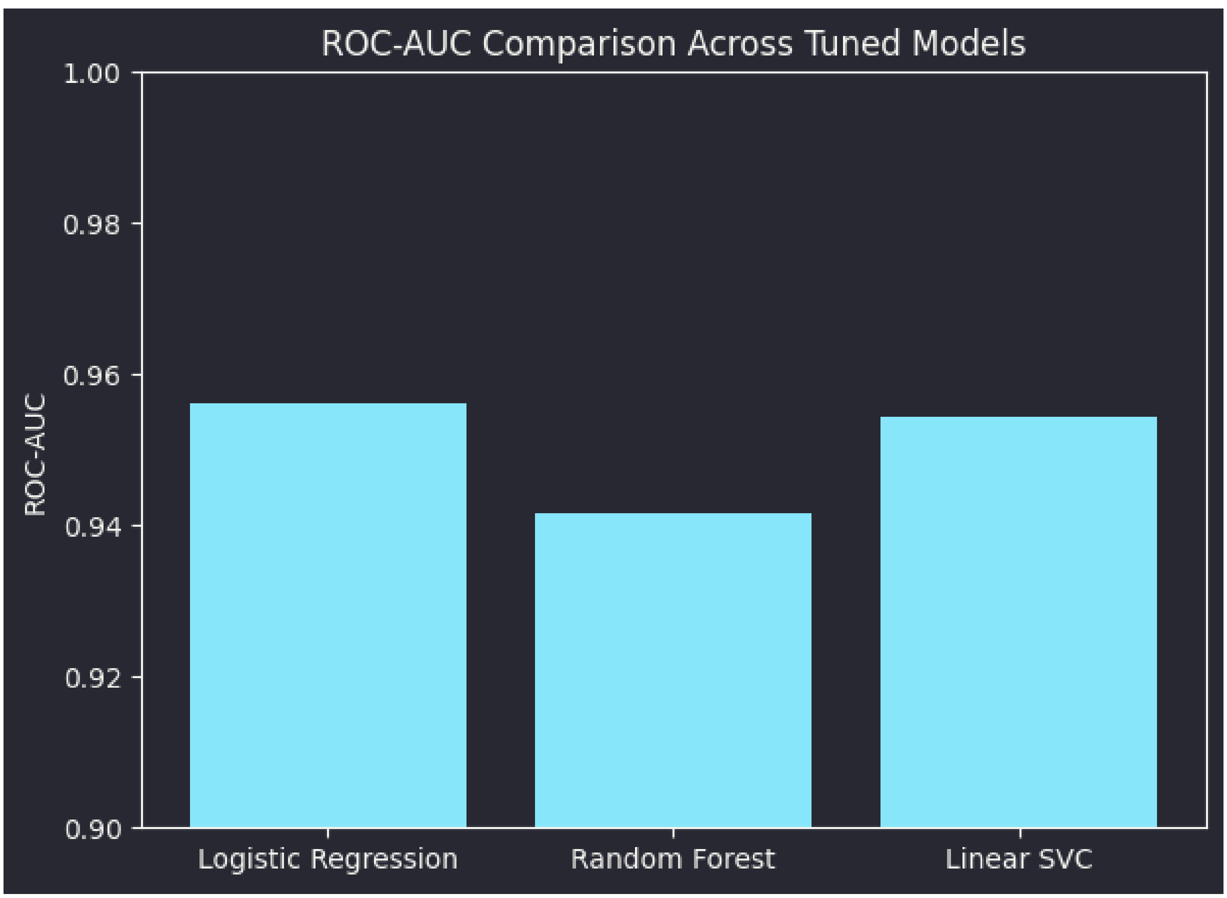
In [92]:
```
models = comparison_df["Model"]
x = np.arange(len(models))
width = 0.35

plt.figure(figsize=(8, 5))

plt.bar(x - width/2, comparison_df["F1 (Negative)"], width, label="F1 (Negat
plt.bar(x + width/2, comparison_df["F1 (Positive)"], width, label="F1 (Posit

plt.xticks(x, models)
plt.ylabel("F1-score")
plt.title("F1-score Comparison Across Tuned Models")
plt.legend()
plt.ylim(0.7, 1.0)
plt.show()
```



The F1-score comparison highlights clear differences in how the tuned models handle positive and negative reviews. Across all models, performance is consistently higher for the positive class, which reflects the class imbalance in the data and the fact that positive reviews tend to follow more uniform linguistic patterns. This indicates that satisfied customers express their opinions in a more predictable way, making positive sentiment easier to classify.

More importantly, the plot shows that logistic regression and Linear SVC achieve very similar and relatively high F1-scores for the negative class, while Random Forest performs noticeably worse. This suggests that the linear models are better at balancing precision and recall when identifying dissatisfied customers, which aligns with the project’s objective of reliably detecting negative feedback. The weaker performance of Random Forest on the negative class further supports the idea that complex, non-linear models do not necessarily provide an advantage for sparse and high-dimensional text data.

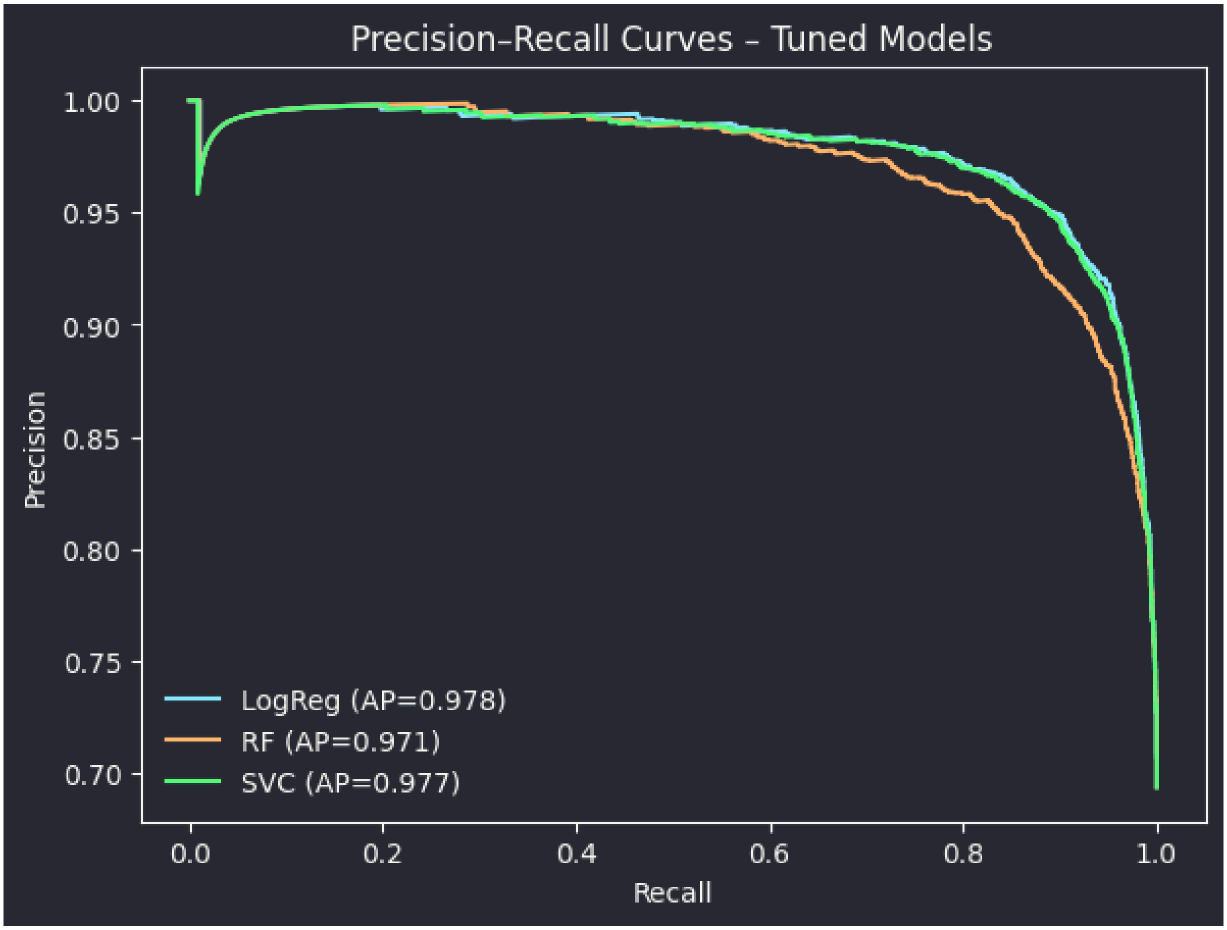
In [93]:
```
plt.figure(figsize=(7, 5))

plt.bar(
    comparison_df["Model"],
    comparison_df["ROC-AUC"]
)

plt.ylabel("ROC-AUC")
plt.title("ROC-AUC Comparison Across Tuned Models")
plt.ylim(0.9, 1.0)
plt.show()
```



The ROC–AUC comparison shows that all three tuned models are able to separate positive and negative reviews effectively across different classification thresholds. Logistic regression and Linear SVC achieve very similar performance, suggesting that linear decision boundaries are sufficient for capturing the main sentiment structure in the review text. In contrast, the slightly lower ROC–AUC of the Random Forest indicates that the additional model complexity does not lead to clearer separation between positive and negative reviews in this setting.

In [94]:

```
from sklearn.metrics import precision_recall_curve, average_precision_score

plt.figure(figsize=(7, 5))

# Logistic Regression
p_lr, r_lr, _ = precision_recall_curve(y_test, results_lr_tuned["y_proba"])
ap_lr = average_precision_score(y_test, results_lr_tuned["y_proba"])
plt.plot(r_lr, p_lr, label=f"LogReg (AP={ap_lr:.3f})")

# Random Forest
p_rf, r_rf, _ = precision_recall_curve(y_test, results_rf_tuned["y_proba"])
ap_rf = average_precision_score(y_test, results_rf_tuned["y_proba"])
plt.plot(r_rf, p_rf, label=f"RF (AP={ap_rf:.3f})")

# SVC (use decision scores)
p_svc, r_svc, _ = precision_recall_curve(y_test, results_svc_tuned["y_score"
ap_svc = average_precision_score(y_test, results_svc_tuned["y_score"])
plt.plot(r_svc, p_svc, label=f"SVC (AP={ap_svc:.3f})")

plt.xlabel("Recall")
plt.ylabel("Precision")
plt.title("Precision–Recall Curves — Tuned Models")
plt.legend()
plt.show()
```



The precision–recall curves show that all three tuned models maintain high precision across a wide range of recall values, indicating strong performance in identifying relevant reviews. Logistic regression and Linear SVC exhibit almost identical behavior, suggesting a very similar trade-off between precision and recall. In contrast, the Random Forest shows a slightly faster drop in precision at higher recall levels, which means it produces more false positives when attempting to capture nearly all relevant cases.

Summary and Conclusions

NOTE!
TF-IDF was done in the clustering part
TF-IDF matrix shape: (18556, 8996)
modeling
evaluation (quality of obtained results)
summary
was the purpose achived?
were the assumptions examined
fromulate conclusions from the obtained result
appendix with source code and data set

logistic regression, random forest, svc

Resources

1. Data source [https://www.kaggle.com/datasets/natashamessier/sephora-skincare-reviews-and-sentiment]
2. Course materials "Text Mining and Social Media Mining" by DR. Karolina Kuligowska and DR. HAB. Jacek Lewkowicz. University of Warsaw, Faculty of Economic Science.
3. Course materials "Sentiment analysis" by Maciej Świtała. University of Warsaw, Faculty of Economic Science.
4. https://www.geeksforgeeks.org/python/introduction-to-emoji-module-in-python/
5. https://www.sketchengine.eu/glossary/type-token-ratio-ttr/
6. Course materials "Machine Learning 1: classification methods" by Michał Woźniak. University of Warsaw, Faculty of Economic Science.
7. Course materials "Machine Learning 2: predictive models, deep learning, neural network" by Ewa Weychert. University of Warsaw, Faculty of Economic Science.